Vol. XLII. DECEMBER, 1899.

AMERICAN SOCIETY OF CIVIL ENGINEERS.

INSTITUTED 1852.

TRANSACTIONS.

No. 863.

THE REACTION BREAKWATER AS APPLIED TO THE IMPROVEMENT OF OCEAN BARS.

By LEWIS M. HAUPT, M. Am. Soc. C. E.

PRESENTED OCTOBER 18TH, 1899.

WITH DISCUSSION.

RESULTS TO DATE.

In a paper published by the Society in the *Transactions** for December, 1898, attention is called to the single curved breakwater at Aransas Pass, Texas, designed and located by the writer for the purpose of creating at that inlet a navigable channel at least 20 ft. in depth.

In the discussion which followed that paper, it appeared that the incompleted breakwater was doing effective work; but as no survey had been made for some time, and the Harbor Company had suspended all work since May, 1897, it was impossible to state the results with any degree of accuracy. The latest examination available at that date was that made under the direction of a Board of Engineers for the purpose

NOTE.—Additional discussions on this paper, received since it was prepared for *Transactions*, will appear in the *Proceedings* for January, 1900, and, together with any further contributions to the subject, will be published in Vol. XLIII of *Transactions*.

* "Origin of the Gulf Stream and Circulation of the Waters in the Gulf of Mexico, with Special Reference to the Effect on Jetty Construction," by N. B. Sweitzer, Jr., Jun. Am. Soc. C. E., *Transactions*, Am. Soc. C. E., Vol. xl, p. 86.

of appraising the value of the work done, with a view of turning it over to the Government to continue. This board reported on November 22d, 1897, that:

"The depth has not been materially, if at all, increased." * * * "At the time of examination of the Board, in July, 1897, it was 8.8 ft., and in November, 1897, 8.5 ft. The depths and contour lines are shown on appended charts."

(These charts, however, show a least depth at one crossing on the crest of the bar of 9¼ ft., November 2d to 5th.) The Board also expressed the opinion that "there does not seem any probability that the jetty as now constructed will of itself secure and maintain any considerable increase of depth in a navigable channel of proper width."

In view of this expectation and the fact that up to the end of February, 1899, a period of 15 months, the unaided currents have increased the depth at this particular part of the bar from "8½ ft.," as reported, to over 22 ft., and that, notwithstanding the existence of a large part of the old Government jetty across the channel, the question may pertinently be asked, whence these phenomenal results in so short a time?

Reaction vs. Concentration.

The answer is plain, since the curved form of the breakwater (not "jetty"), is such as to develop the potential energy of the ebb currents, rendering them kinetic, and applying them locally on the crest of the bar where they are needed for scour. At the same time, the breakwater serves to arrest the littoral drift and defend the channel from its encroachments. In short, it aims to utilize the well-known centrifugal force by the reaction developed by the resistance caused by a continuous change of direction so often manifested in the concave bends of streams, instead of the principle of concentration which has been relied upon so largely in the system of twin or convergent jetties, with such meager results.

This may be well illustrated, perhaps, by the case of a projectile flying through the air with a large amount of stored energy, which is developed suddenly only when meeting with a point of resistance. It has also been observed that currents having a velocity sufficient to scour the material over which they are flowing do not disturb it, but if a resisting log, rock or other obstruction is introduced, the obstruc-

tion is undermined and often buried and covered up by the reaction which it develops in the currents.

In Ex. Doc. 78, 48th Congress, it is stated that "The mean ordinary velocity at the Narrows (New York Bay), is, during the ebb tide, about 2 ft. per second, and from this a depth of 100 ft. results." This does not follow, as there are numerous sandy bars having a much greater mean velocity over them which lie at depths less than 10 ft. from the surface. Manifestly, it is not velocity, therefore, that constitutes the working force to produce scour, but reaction, just as when impounded waters are dammed back prior to escaping through a breach, when the ncreased head and contraction react upon the bottom, affecting the entire volume and producing deep eddies. In the case of a single obstructing pier head, the effects will often extend to depths of 50 ft. or more, depending on the intensity and direction of the currents, scouring out the material and depositing it in the lee of the pier. In the case of the Narrows, above cited, it is not the ebb which scours, but the flood current, the resultant of which is near the bottom and which runs for eleven hours out of twelve up stream or into the Upper Bay, indicating a huge vertical eddy.*

The principle of concentration or trailing by convergent or parallel jetties, on the other hand, has been applied frequently by maritime engineers, but generally without producing the desired results unless aided by dredging. The most successful instances of this method are those at the mouths of large rivers which debouch into nearly tideless seas, as at the Sulina mouth of the Danube, built by Sir Charles Hartley; the South Pass, by the late James B. Eads, M. Am. Soc. C. E., and the Tampico jetties, by E. L. Corthell, M. Am. Soc. C. E.; but for purely tidal entrances the effect of the two jetties is to invert the natural trumpet-shaped opening and to diminish the area of the gorge, which is transferred to the crest of the bar, thus reducing the tidal volumes, preventing the complete filling of the interior compartment and requiring the same volume to move in both directions over the same path. The effect, therefore, is to minimize the movement and reduce the resultant to zero. Probably the most successful tidal harbor improved by convergent jetties is that of Dublin, where the improvement is largely due to a gap of 600 ft. left in the "Great North Wall," or jetty, near its shore end, to admit the flood tide

* Ms. Report of Professor Henry Mitchell, U. S. C. & G. Survey Office, or "Harbor Studies" by the author. Library. Am. Soc. C. E.

which passes over the North Bull Sands, and which flows out chiefly through the jetties because of the form of the basin and the great range of the tides, which is there about 13 ft.

The following extracts from a paper read May 20th, 1879, by John Purser Griffith, Assoc. M. Inst. C. E., on "The Improvement of the Bar of Dublin Harbor by Artificial Scour," will serve to illustrate this point:

"Mr. Giles recommended that an opening should be left at the shore end of the proposed wall 600 ft. wide, to allow of a free passage for the tidal waters north of the Green or Bull Island, as the sand island on the North Bull was called. This opening had been proposed by Captain Corneille in 1802; but at that time the Directors General of Inland Navigation feared that the flood tide flowing through this opening would carry sand from the North Bull into the harbor, and that the injury thus done to the port might more than counterbalance any advantage to be gained by the opening.

"In 1835 Sir William Cubitt reported upon the state of the harbor. Referring to the improvement of the bar, he says: 'The great increase of depth and improved channel over the bar I attribute entirely to the erection of the Great North Wall, a measure founded upon sound principles, and carried into effect in a manner well calculated to effect the desired purposes—viz., that of checking the influx of sand upon the flood tide from the North Bull into the harbor, and giving an increased impetus at the ebb tide by means of narrowing the stream, and confining it to a direction suitable for keeping open the best channel, the effect of which is already shown by an increased depth of 5 ft. over the east bar since the erection of the Great North Wall.'

"Captain Washington, in his report, written in 1845, on the harbor of Dublin, as one of the Tidal Harbors Commissioners, referred to the Great North Wall as follows: 'The propriety of this measure, which involved so heavy an expenditure, has been a subject much controverted amongst persons connected with the port; but it is believed that there is now but one opinion as to its beneficial effects, and that the plan evinced both good judgment and skill.'

"There are few, if any, similar cases of a bar and entrance channel to any harbor being increased in depth like that of Dublin, viz., about 7 ft. in thirty years, and I think great credit is due to those who designed, as well as those who executed works which have achieved so important a result.

"The improvement of Dublin Harbor entrance ranks second to none. There is no other example, so far as the author is aware, of the construction of an artificial estuary for scouring purposes which has proved so successful.

"In the discussion, Mr. Abernethy, Vice-President, said he thought

attention should be directed to the construction of works which would tend to increase the tidal volume, and at the same time to prolong the action of the outgoing currents from the period of half ebb towards low water.

"Mr. Bergeron stated it was very difficult, almost impossible, to dredge sand bars in an open sea.

"Mr. Vernon-Harcourt said that to diminish the tidal capacity within a harbor was the worst thing that could possibly be done.

"Mr. Griffith said: 'Prior to the construction of the Great North Wall the ebb of a spring tide attained a velocity of 1¼ miles per hour across the bar, while at present it reached nearly 3¼ miles, showing an increase of about 2 miles per hour. He did not believe that very high velocities were efficient. Several instances might be named in which high velocities were attained, and yet the scour was a failure.'

"Mr. Stoney thought that though there might be some doubt as to the authorship of the Great North Wall, there could be none as to its complete success."

From this quotation it appears that some of the best authorities in the world recognize an increase in depth of 7 ft. in thirty years as being beyond precedent, yet at Aransas Pass, with an incompleted reaction breakwater, having large gaps at both extremities, a feeble tide (only 14 ins.), and a serious submerged obstruction almost completely blocking the channel, the depths have progressively increased from about 6 ft. to an average of over 18 ft. in a few years, while in some places there are depths of 23 ft.; so that instead of a deepening at the rate of 1 ft. in over four years, the figures are reversed and show over 4 ft. in one year, a rate which is about twenty times greater than the best heretofore recorded.

These results are the more remarkable as they have been obtained without the aid of dredging, and on a bar which is composed of hard, fine sand, so compact that a boat hook or the blade of an oar does not penetrate it; so solid is it, that a Board of Engineers, in 1889, said of this bar that "The necessary results could not be obtained without extensive and almost constant dredging, which would involve incalculable expense."

As early as 1871, the project of obtaining a navigable channel over the Aransas Bar was pronounced impracticable because of its cost. The report of the United States Engineers of 1871 stated that "The cost of building a jetty, from Mustang or St. Joseph's Island towards the bar, which would be able to resist the action of the storms upon the quicksand foundation, must be an insuperable objection to any

such experiment;" yet it was finally considered expedient, and it was further estimated in 1879 that, to obtain a 12-ft. channel would cost \$759 185. (The ruling depths are 8 to 8½ ft.) Work was commenced on this project in 1880 and, after an expenditure of \$550 416, up to June, 1890, it was discontinued, with a resulting depth of 7½ ft. In 1887 the project was modified "to secure and maintain a channel depth of not less than 20 ft.," and the same report stated that "The original estimated cost of this work, as here revised, is \$2 052 543.72."

Cost of the Reaction Breakwater.

As the Government abandoned the work at Aransas and concentrated its appropriations on Galveston, a private company, known as the Aransas Pass Harbor Company, was incorporated, March 22d, 1890, and soon thereafter secured a large land bonus and proceeded to construct another jetty which, like its predecessor, was erroneously located on the southerly side of the Pass. It proved to be a failure, as was predicted, but seemed to be a necessary part of the experience of the Company.

At a later date the Company was reorganized, and it was then decided to give the reaction breakwater a trial by building only half of it, for which half depths of 15 ft. were predicted. Work was commenced in August, 1895, and in a few months the bar deepened to 13 ft.; but, unfortunately, the remains of the original Government jetty were then uncovered and found to be still in place, lying across the proposed channel, although previously officially reported to have "disappeared." The building of the breakwater to high water intersected this old work and formed a pocket which arrested the sand and prevented scour, while the Harbor Company failed to remove the obstructing jetty, as advised to do, until the winter of 1896-97, when a contract was made with Col. C. P. Goodyear to complete the work, he to advance all the funds and assume all risks.

He exploded some 23 350 lbs. of dynamite on the old jetty and bar, causing a breach of about 500 ft. in length near the breakwater, but being unable to secure the capital in time to continue the work, he was reluctantly obliged to surrender his contract in May, 1897. Since that time no work has been done. About ¼ mile of the breakwater near the center was built to full dimensions; the shore flank was extended to its minimum limits, but of a contracted section, with large

gaps through which the ebb currents escaped seaward and the sand entered the channel during flood tide, and the mat was laid at the outer end to a distance of 1 000 ft. All this work was done by Charles Clark & Company, of Galveston, and notwithstanding the storms, which have been violent, and the alleged quicksand, there is no appreciable loss or shrinkage in the sections of the structure, which has stood more than three years, in a very exposed position, doing excellent service.

The total length of the structure as designed is 6 200 ft., and about $250 000 has been expended on it.

The quantities were:

Rip-rap (core)	47 246	cu. yds.
Cap stones	9 183	"
Mattress work	17 000	"
	73 429	"

Say 75 000 cu. yds. at $3.33 per yard, and the cost per foot of depth gained, to date, has been approximately $25 000. It would, doubtless, have been much less but for the old jetty, which is still a serious obstruction and menace in the navigable channel.

As the total length of this work is less than half that required by the parallel-jetty system, it is evident that its cost will be much less while its efficiency is much greater, as it creates and maintains its own channel.

An official report of a thorough survey made in January and February, 1899, by the United States Coast and Geodetic Survey states, *inter alia:*

That during the winter the weather was so bad that it was only practicable to get on the bar for survey purposes about one day out of each week, and that "very heavy gales prevailed with terrific force with the wind from the north-north-east."

"In 1895 the Aransas Pass Harbor Company constructed a jetty in the shape of the letter S on the north side of the entrance, which is still in existence, and ever since its construction there has been a marked increase in the depth of water on the bar. The present channel crosses the Mansfield jetty, portions of which are still in existence. An attempt was made to remove this by explosion of dynamite, with the result that the rocks scattered over considerable area, and without doubt they prevent the current from scouring the bottom to its full capacity. * * * It is my opinion that by the completion of the

present jetty and the clearing away of the rock in the entrance that a channel of at least 20 ft. in depth would soon be secured."

This report, taken as a whole, confirms in every particular the predictions of the inventor as to the results to be expected and the features embodied in a breakwater of this peculiar form and position.

The conditions which this structure was designed to fulfill were:

1. That it should arrest the littoral drift of sand and defend the channel from its encroachments—hence it must be placed to "windward" of the proposed channel.

2. That it should freely admit the full tidal prism during the entire period of flood tide, that there might be no reduction of volume at ebb; consequently it was detached from shore, there being a gap of nearly 1 800 ft. left open at the inner end.

3. That it should catch and control the greater part of the discharge at ebb and confine it locally to a narrow path across the bar, thus changing the conditions of equilibrium of the tidal movements largely in favor of the ebb.

4. It should be a compound and reverse curve, concave to the channel, and have such radii as to produce the best dimensions of waterway consistent with the volume of discharge, so as to develop a continuous reaction entirely across the bar and at the same time afford a good navigable channel.

5. It should also be so adjusted, with reference to the axis of the discharge, as to receive the same tangentially and train it across the bar without creating abrupt points of incidence, causing inequality of depths, and, at the same time, not producing so much compression as to cause undermining and ultimate destruction or large expense for maintenance.

6. It should also control a sufficient volume to prevent any encroachment of drift from the opposite side of the channel during the season of change in the direction of angular wave movements, and thus construct its counterpart of sand to aid in controlling the currents, without cost.

7. It should not promote the growth of the bar seaward by the deposit of the material removed from the channel on the outer slope of the bar.

8. It should rise above high water to afford an aid to navigation by breaking the waves and indicating the position of the channel.

9. It should be so located as to develop the channel across that part of the entrance where the bar-building forces are weakest, thus giving quicker and more permanent results.

That this single, detached, reaction breakwater fully satisfies the foregoing requirements, even under adverse circumstances and in an incomplete state, is demonstrated sufficiently by the work done at Aransas Pass, as shown by the progressive deepening and enlargement of the channel since the breach was made in the old Government jetty by Colonel Goodyear in 1897. That it is a stable, permanent and economical structure is also shown by the condition of the work after tests by severe storms and by years of exposure. That it has a remarkable power of producing erosion is shown by the fact that in February, 1895, the distance across the bar between the 15-ft. contours on the inside and outside was 3 650 ft., or nearly $\frac{3}{4}$ of a mile, which has been cut through except a few hundred feet, giving a navigable channel at mean low water of over 14 ft., and without material advance of the bar seaward.

It is not doubted by competent authorities that if the breakwater had been completed in the ten months, as originally proposed, and the old jetty had been promptly removed when discovered *in situ*, the predicted 20 ft. would have been secured ere now, and without aid from dredging, while the channel would have been self-maintaining.

In short, this simple structure marks a distinct advance in the resources of maritime engineers in the improvement of ocean bars, with great economy in cost of construction and maintenance, and large saving of time. It is the result of about 25 years of research and over 11 years of effort to secure a practical demonstration, and it has now reached a point sufficient to prove its great utility.

It is but just to add that these unprecedented results were probably unknown to the Board of Engineers which stated in 1897 "that the value to the Government of the works of the Aransas Pass Harbor Company for the improvement of Aransas Pass, Tex., is nothing," and that the same Board in reporting on the same subject December 17th, 1898, therefore urged the removal of the outer 1 000 ft. of foundation; the construction of a sill 40 ft. wide and 3 ft. deep, which would have obstructed the tides by closing the opening at the shore end; the construction of a parallel straight jetty on the southerly side of the channel and other works, supplemented by the dredging of 750 000 cu.

yds. at an estimated cost of \$1 525 000. This estimate was met by a proposition from a responsible firm of contractors to guarantee the 20-ft. channel within two years at a cost of less than half of the above sum, with the result that Congress concluded to appropriate \$60 000 to remove the obstructing portion of the old Government jetty, and permitted the incomplete breakwater to remain unmolested, that it might continue to deepen the channel by natural agencies and so further demonstrate its utilities. At that date the reported depth was 13 ft. 4 ins., while since then it has increased, within a few months, to about 18 ft. at the same point, thus confirming the wisdom of this action. With the gaps closed and the structure completed, there should result, in a short time, the full depth of 20 ft., as predicted, and at a cost considerably less than half of that of the parallel jetties, as originally proposed. The manifest economies of this method should suffice to commend it for more general use in the improvement of bars on alluvial coasts where there is a resultant littoral drift.

The writer desires to acknowledge his indebtedness to H. C. Ripley, M. Am. Soc. C. E., and George Y. Wisner, M. Am. Soc. C. E., consulting engineers, for assistance in preparing the specifications and for their unshaken confidence in the results to be expected from this plan from its inception, as well as to Colonel C. P. Goodyear for his successful effort to breach the old jetty, and thus enable the partially controlled currents to reach the crest of the bar.

The work was done under the efficient supervision of William Dunbar Jenkins, M. Am. Soc. C. E., resident engineer for the Harbor Company, and his assistants, Messrs. Pitts and Collins.

APPENDIX.

THE THEORY OF THE REACTION BREAKWATER.

It was the purpose of the writer to submit only a brief statement of physical conditions and results secured under very adverse circumstances, but, in deference to the opinions of the Committee on Publications, a digest of the researches which led to the development of this form of breakwater is added to supplement the subject.

The numerous and conflicting conclusions, reported after careful instrumental surveys made to determine the direction and intensity of the forces operating upon ocean bars, led the writer to give them but little weight, and to conclude that the best guide in such cases was to be found in a correct interpretation of the resultant hydrographic features as revealed by a study of comparative charts. This method is best applied to alluvial coasts where the material, being more or less mobile or plastic, is moulded by the ever-varying forces of winds, waves, tides and currents, the resultant effect of which is manifested by the form, size and location of the adjacent and submerged shoals, dunes and other features; in short, it is a deduction of cause from effect and is characterized by certain typical forms and directions of movement, so that a comprehensive as well as detailed study of the records covering an extended period of time are important factors in solving problems of this class.

The writer, therefore, gave considerable time to the investigation of the literature and charts pertaining to harbor inlets, both at home and abroad, making personal visits to the more important works, and was surprised to find how small a percentage were designed with a view to utilize the natural forces for deepening and maintenance. He prepared several papers discussing and classifying these problems, which have appeared in various scientific periodicals.*

* "Harbor Studies." *Proceedings*, Engineers' Club of Philadelphia, Jan. 16th, 1886.

"The New York Entrance." *Proceedings*, Engineers' Club of Philadelphia, Feb. 6th, 1886.

"The Delaware Breakwater." *Proceedings*, Engineers' Club of Philadelphia, Feb. 20th, 1886.

"Problem of the New York Entrance." *Proceedings*, Am. Assoc. for Advancement of Science, Aug. 20th, 1886.

"Improvement of Tidal Rivers." *Journal* of the Franklin Inst., Sept., 1887.

"Improvement of the Port of Philadelphia." *Journal* of the Franklin Inst., Oct., 1887.

"The Physical Phenomena of Harbor Entrances: Their Causes and Remedies." *Proceedings*, Amer. Phil. Soc., 1888. (This paper received the award of the Magellanic Premium, Dec. 16th, 1887.)

"Discussion of the Dynamic Action of the Ocean in Building Bars, etc., being a reply to Report of the Board of Engineers, U. S. E." *Proceedings*, Amer. Phil. Soc., March, 1889.

(*This list continued in the foot-note to page 498.*)

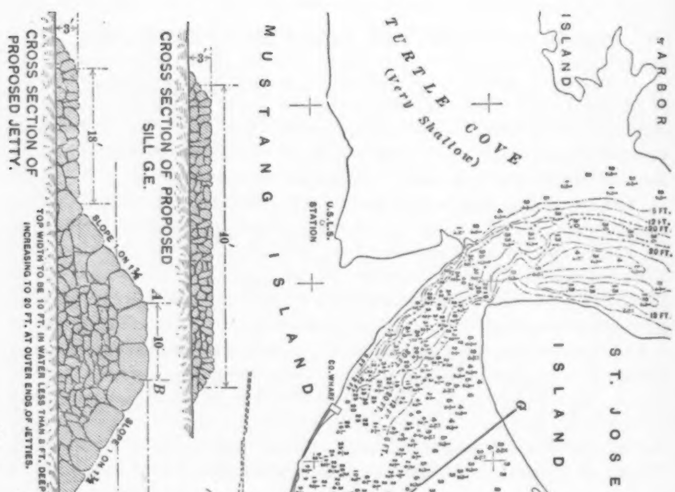
PLAN OF IMPROVEMENT
OF
ARANSAS PASS,
TEXAS.
AS PROPOSED BY BOARD OF ENGINEERS, U.S.A.
Soundings, Shore-lines and positions of works already constructed, taken from Chart No. 3 submitted by Board of Engineers,
SCALE OF FEET
ST. JOSEPH
ISLAND
HARBOR
ISLAND
TURTLE COVE
(Very Shallow)
MUSTANG ISLAND
U.S.L.S. STATION
CO. WHARF
NORTH JETTY BUILT BY
ARANSAS PASS
OLD GOVERNMENT JETTY
WRECK OF MARY
CROSS SECTION OF PROPOSED SILL G.E.
CROSS SECTION OF PROPOSED JETTY.
TOP WIDTH TO BE 10 FT. IN WATER LESS THAN 8 FT. DEEP INCREASING TO 20 FT. AT OUTER ENDS OF JETTIES.
LINE OF MEAN LOW WATER

FIG. 1.

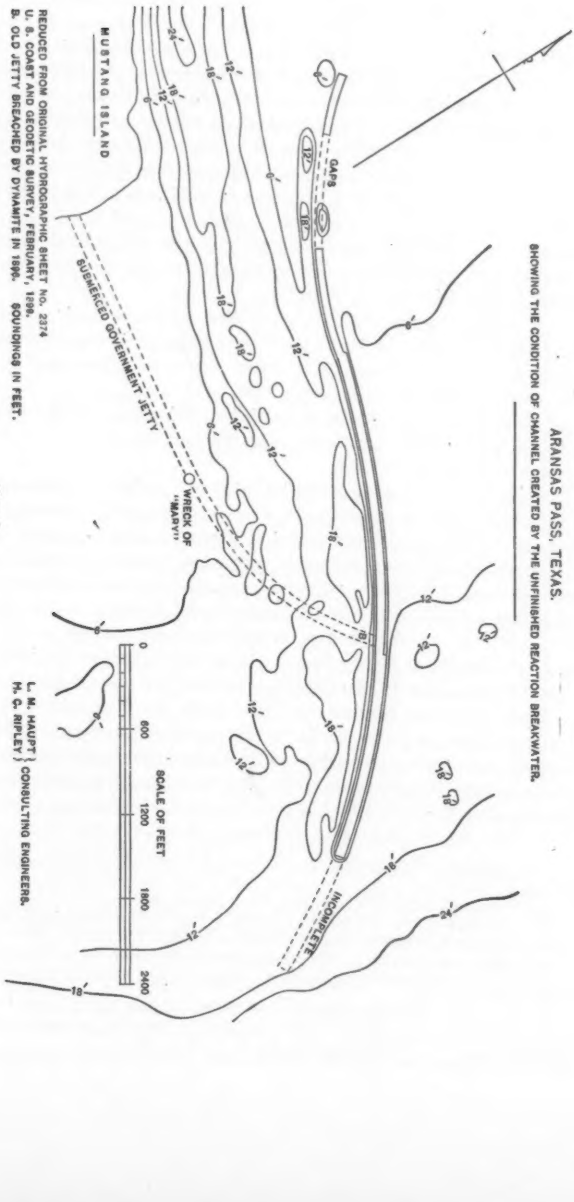
ARANSAS PASS, TEXAS.
SHOWING THE CONDITION OF CHANNEL CREATED BY THE UNFINISHED REACTION BREAKWATER.
GAPS
SUBMERGED GOVERNMENT JETTY
WRECK OF "MARY"
INCOMPLETE
MUSTANG ISLAND
SCALE OF FEET
0
600
1200
1800
2400
L. M. HAUPT
H. C. RIPLEY
CONSULTING ENGINEERS.
REDUCED FROM ORIGINAL HYDROGRAPHIC SHEET No. 2374
U. S. COAST AND GEODETIC SURVEY, FEBRUARY, 1898.
B. OLD JETTY BREACHED BY DYNAMITE IN 1896. SOUNDINGS IN FEET.

Fig. 2.

The result of these investigations led to the following conclusions:

(1) That in many places there were cyclic movements of the bars and channels produced by the resultant of the external littoral forces which were the bar-building agents, and which predominated over the internal or ebb currents which were the bar-destroying elements.

(2) That maritime engineers, in their efforts to improve purely tidal entrances, had greatly reduced the tidal energy by constructing two parallel or convergent jetties from the shore line to the bar, thus obstructing the free ingress of the tide upon which they were dependent for both volume and velocity at ebb, and that such construction confined the movements at all stages of both ebb and flood to the same path across the bar, thus producing no changes of equilibrium in favor of the ebb and requiring constant expense for bar removal and maintenance between jetties by dredging.

(3) That in the construction of jetties, where there is a resultant littoral drift, the wrong one is sometimes built first, thus arresting the drift and causing the bar to advance seaward (in one case nearly 3 miles), thus greatly increasing the cost.

(4) That no attempt had been made to utilize the reaction principle to effect a local scour across an ocean bar similar to that existing in all concave bends of streams.

The writer, therefore, believed that, by a radical departure from the existing practice, there were numerous localities where a single structure of proper form and position might be made to utilize all the available forces of Nature to assist in creating a better channel across ocean bars and fulfill all the requirements as set forth in the first portion of this paper, but as no precedent existed and he must needs establish the correctness of the theory, applications were made in January, 1888, to the Board of Engineers, U. S. A., for a report on his plans, followed by requests to the Chiefs of Engineers, under dates of June 30th, July 30th and September 14th, 1888, for permission to make a demonstration, at a site to be agreed upon. These requests were never even acknowledged, although the letters were doubtless received, since they were not returned, while the Board made an adverse report to the Chief of Engineers on March 16th, 1888, concluding with these words: The Board finds that Professor Haupt's views "are purely

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"Fire Island Inlet: Is it Moving East or West?" *Journal* of the Franklin Inst., April, 1889.

"Report on the Harbor of Wilmington, Del." March, 1888.

"Jetties for Improving Estuaries." *Journal* of the Franklin Inst., April, 1888.

"Harbor Bar Improvements." *Journal* of the Franklin Inst., July, 1889.

"Galveston Harbor Problem." *Journal* of the Franklin Inst., Oct., 1891.

"How to Obtain Deep Water on the Gulf." Pub. Doc. S. 1583, 51st Congress, 1st Session, Jan., 1891.

"Plans for Improvement of Entrance of Rio Grande do Sul, Brazil," 1888.

"Littoral Movement of the New Jersey Coast, with Remarks on Beach Protection and Jetty Reaction." *Transactions*, Am. Soc. C. E., Sept., 1890.

(Most of the papers cited in this list will be found in the library of the Society.)

theoretical, are unconfirmed by experience and contain nothing not already well known, which has a useful application in the improvement of our harbors."

The writer only learned of the existence of this report by accident at a later date, when it was quoted against his plans. He then discussed the report, forwarding copies thereof to the members of the Board and the then Chief of Engineers, but received no reply. It was therefore impossible to "confirm the theory by experience," and there was no alternative but to await a favorable opportunity, which did not arrive until 1895, when, everything else having failed at Aransas Pass, where over $500 000 had been spent by the Government in futile efforts to secure 20 ft. of water, a private party finally concluded to build half of the reaction breakwater on a predicted depth of 15 ft. for this part of the work. This depth has now been exceeded, but only after a breach was made in the obstructing Government jetty, officially reported to have disappeared prior to the beginning of the work. The partially controlled currents have actually removed about 400 000 cu. yds. of compact sand from the bar without the aid of a dredge or other mechanical appliance, and have prevented the deposition in the channel of a much larger volume driven along the coast by the angular wave movements.

The theory, therefore, which has been successfully applied at this admittedly difficult and unpromising location, was to protect the bar crossing near its weakest point from the drifting sand by a resisting mass of rock so placed as to develop a continuous reaction across the bar by the ebb currents, preventing their expanding over the entire external sector and conserving the energy of the effluent stream until it reached the deep water of the Gulf.

As means to this end the breakwater is detached from the shore to permit the tidal compartments of the inner bays to be filled freely by each flood; it is also composed of curves whose radii and centers are adjusted to the site in such manner as to cause deposits on the outer side of the structure, thus re-enforcing it, and scour on the inner side, where an excess of foundation material revets the slope, and a peculiar order of construction is adopted, whereby the scour is assisted by gravity and the advance of the bar seaward is prevented.

All these results appear to have been fully secured by the work thus far done, as is shown by the Coast Survey report of February, 1899. Modifications, however, are always to be expected in depths due to variations in the natural forces, but the progressive deepening created by the currents gives every assurance of their ability to maintain the channel they have already created and which would be still further deepened by the completion of the work as designed.

The modifications submitted to the last Congress by two members of the Board of Engineers in their report of December 17th, 1898, are

shown in Fig. 1, from which it appears that it was proposed to return, as nearly as might be, to the old-time method of two, nearly parallel, jetties and the closure of the beach entrance, supplemented by dredging, at a cost of over $1 500 000. This plan, if adopted, would destroy the effective energy of the currents and prevent the completion of the demonstration of the principles which have been applied thus far at this entrance with unprecedented success, and would further involve an annual expense for maintenance, which is not now required.

This proposition, however, was rejected by Congress, which, as stated, made an appropriation of $60 000 to remove that portion of the old Government jetty which crossed the channel and provided that no portion of the reaction breakwater should be disturbed. This work was recommended by the United States District Engineer, June 8th, 1899, and was authorized July 11th, 1899, but, up to the latter part of September, the work had not been advertised to be let.

As a part of the evolution of the improvement of ocean bars and in confirmation of the theory, the writer desires to add that independent efforts were being made by others in the same direction and with substantially the same conclusions as to the primary importance of arresting the littoral drift and of concentrating the scouring force by a single curved breakwater instead of controlling the ebb movements by means of two jetties. As early as 1883, Mr. H. C. Ripley, then United States Assistant Engineer to Colonel S. M. Mansfield, stationed at Galveston, Tex., designed a concave, detached breakwater for that entrance, to be placed on the windward side of the channel, which was approved by Colonel Mansfield and recommended to the Chief of Engineers for adoption, in a letter dated March 19th, 1884. This design is shown in the Report of the Chief of Engineers for 1884, opposite page 1300, and designated: "Site of North Jetty, proposed by Colonel Mansfield."

This coincidence, in connection with Mr. Wisner's work, both at the South Pass and at the mouth of the Brazos, led to the formation of the Board of Consulting Engineers for Aransas Pass by Mr. Brewster Cameron, which consisted of H. C. Ripley, George Y. Wisner and the writer. Their predictions have been fully verified by the results secured by natural scour after the partial removal of the unexpected obstructions.

Á propos of the severe floods in the basin of the Brazos River, Texas, in July, it was expected that the larger volume discharging with greater velocity over the bar at its mouth between parallel jetties would materially improve the depth. On the contrary, the soundings showed but 15 ft. in several places, thus demonstrating the relative superiority of the principle of reaction by a single jetty, as applied at Aransas, to that of concentration by twin jetties at the Brazos River bar.

DISCUSSION.

E. L. CORTHELL, M. Am. Soc. C. E. (by letter).—The writer hesitates to discuss this paper for the reason that it deals with an uncompleted work, which is so exceptional, as to the theory upon which it is based, that the paper describing it seems to be prematurely issued and unsatisfactory for discussion. Mr. Corthell.

The writer desired sincerely that the means should be furnished to complete the work according to the plans of its designers, in order that it might be demonstrated whether the peculiar theory upon which they are based is correct; for the cost will be only about one-third of the usual cost of obtaining deep water over sea bars.

The author, however, has had the boldness to attack the methods generally adopted hitherto, and he has advanced certain theories and made certain claims for them, and in so doing has necessarily criticised plans based on other and opposed theories. It is, therefore, necessary to consider the paper carefully, which, however, the present engagements of the writer do not permit him to do; he can only hastily give a *résumé* of the subject.

The terms used and the words coined by the author are not entirely understood by the writer, and he may not be correct in translating them into common language.

It is not quite clear what the word "reaction" means, or such an expression as this, "the curved form of the breakwater is such as to develop the potential energy of the ebb currents, rendering them kinetic." It is easily understood that a current impinging against the concave bank of a river scours out the bed near the bank, but just how this can exist in the case of a convex bank is not so easy to understand; for it must be remembered that one of the essential features of this work is its "S"-form—a "compound and reverse curve."

It might be expected in a river that a current passing from one concave bank to another concave bank, as is the case at the Aransas channel, would necessarily make what river men call a "crossing," and that on this crossing, or reversion point of the current, there would be a slackening of the velocity and a deposit of sediment. There seems to be such action going on at Aransas and a shoaling at this reversion, which no doubt will always exist and will give a limited depth at that point unless it is deepened artificially.

The entirely new idea that "it is not velocity * * * that constitutes the working force to produce scour, but reaction" is so entirely opposed to all accepted ideas of river and harbor engineers and their experience, that it is difficult to understand.

The writer, in the course of the last 25 years, has had occasion,

Mr. Corthell. not only to build works, but to examine many personally, not only in this, but in other countries, as well as to conduct an extensive correspondence with engineers engaged on similar works, and he must say that the views of the author are not, he believes, in accord with successful practice. The writer will not say that a single-legged, worm jetty would not, in some situations, obtain the desired results, but to adopt it as a general principle is, he believes, unsound.

The author refers, for confirmation of his views, to the Dublin harbor works, which the writer has examined, but has found so entirely different in conditions and plans from those at Aransas that he does not see the force of the comparison. The tidal opening at the land end of the North Wall at Dublin is only 600 ft. long, and the dike itself is 9000 ft. long. The tides in Dublin Bay not only rise 13 ft. as against a little over 1 ft. at Aransas, but this great range of tide—which, by the way, is semi-daily, instead of daily, as at Aransas—and the local configuration of the shores cause peculiar and opposing currents, which this opening and the direction and extent of the "North Wall" took advantage of; and—which constitutes the greatest difference—there is a solid wall 16 000 ft. long on the opposite side of the channel connected with the main land, all above water.

It is to be noted, further, that the channel, formed so successfully by scouring action through the bar, is at the narrowest place between the two jetties, and that where the "North Wall" flares away from the "South Wall" and leaves a very wide opening, the entire distance has to be dredged continually to make and maintain the depth. In fact, from the bridge at Carlisle Street, in the port, to within 1 000 ft. of the sea end of the "South Wall," which is the guiding and longest jetty, the improvement in the channel is due solely to dredging, the effect of the scour being inappreciable.

One purpose of the Aransas breakwater is to "arrest the littoral drift," and for this purpose it is built on the "windward" side of the channel. The author presents no data to show that the "windward" side is the north and east side. The writer's recollection is that the preponderance of winds is from the south and west, and that the winds and the currents are up the coast during most of the year. However, that is a matter of fact to be ascertained from the anemometer records at Aransas or Galveston. As to currents in the Gulf of Mexico, the writer believes the following to be generally the conditions:

The current enters through the Yucatan Channel, and goes out through the Florida Channel—so far, at least, as surface currents are concerned. The former moves up the coast, hugging it in the Bay of Campeachy, past the mouth of the Coatzacoalcos River at the Isthmus of Tehuantepec, past Vera Cruz, and then begins to spread out into the great area of the Gulf. Nearing the mouth of the Mississippi,

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but still some distance off, it gathers itself together for its passage through the Florida Straits, its velocity gradually becoming greater. All along this part of the coast there is a reactionary or eddy current which moves in the opposite direction, and which is felt as far west as Galveston and the mouth of the Brazos, though with much diminished force. At Aransas there is no appearance of the Gulf Stream for probably 150 miles off shore; it is opposite the widest expansion and the slackest current of the Gulf Stream. The winds cause the currents, and but little reliance can be placed on the westward drift. For this reason the opening which is left between the jetty and the land is of only theoretical advantage, and the writer believes it to be a positive, practical disadvantage. This was his contention in reference to the old plans at Galveston, and, as a lesson from these works, the following is abstracted from his paper on the South Pass Jetties:*

The flood volume of the river, and the full volume of the tides, are the powers which the engineer should call to his aid. Lateral outlets near the land should not be provided. Ostensibly, they are for the purpose of letting the tides into the bays, but it is through them at the ebb that they seek to find the lower level of the sea, instead of taking the longer and more difficult course along the inside of the works, where there is a pronounced frictional resistance to current movement.

This important feature of harbor improvement was explained so clearly by the late James B. Eads, M. Am. Soc. C. E., in his discussion of the writer's paper that it will be useful to refer to it in order to set ourselves right on this point.

The writer has made a special study of most of the river mouths and harbor entrances on the North, Baltic and Zuyder Seas—there are over 25 of them—and he knows of no instance where there are not two jetties contracting the channel-way and concentrating the fluvial or tidal flow. These parallel jetties are not always equal in length, but there are always two of them; and while in the nearly tideless seas of the Baltic and the Zuyder Zee dredging has to be done to some extent, there is no doubt whatever that the two jetties are the cause of the successful maintenance of the deep channels which have been maintained there for many years, the depths of which are gradually increased to accommodate the increasing drafts of vessels.

Further, before quoting Mr. Eads' discussion, the writer desires to state some facts, in reference to the Tampico harbor works, which may have a bearing on the "reaction" theory of the author. They will at least furnish a remarkable proof of the correctness of Mr. Eads' views, expressed seven years before their occurrence. The details of the history of the Tampico works will be found in the *Proceedings* of the Institution of Civil Engineers.†

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* *Transactions*, Am. Soc. C. E., Vol. xiii, p. 326.

† *Minutes of Proceedings*, Inst. C. E., Vol. cxxv, 1895-96, pp. 243-262.

Mr. Corthell. The Pánuco River, which flows into the Gulf of Mexico at Tampico, is one of the largest in Mexico. The area of its water-shed is about 36 000 square miles. The periodicity of its floods is very variable. Sometimes there is a period of 3 to 5 years between them. The works at the mouth of the river consist of two parallel rectilinear jetties, 1 000 ft. between center lines. They are built of rough stone, with a foundation and hearting of mattress work. The depth on the bar about one mile from the shore was about 8 ft.

The works were pushed to completion with great rapidity. They were completed in December, 1892. Two or three small rises, and the tidal flow had deepened the channel to about 17 ft.

In July, 1893, a heavy rise came. It found its usual outlet partially dammed—walls on the sides and a bar between. It raised the surface of the water at least 2 ft. at Tampico, 7 miles from the Gulf; but the force brought to play upon the bar was tremendous. Slope observations made during the rise—which lasted from July 12th to August 1st—showed that the fall of the surface at the sea end of the jetties varied from about 0.5 to 2.75 ft. per mile. The velocity was over 8 miles per hour. The total amount of material scoured out of the bar and discharged into the sea in that flood was 1 201 985 cu. yds., in addition to about 7 500 000 cu. yds. of suspended matter.

The "reaction" upon this bar by these forces consisted simply in moving a great volume of water down a steep slope; it acted vigorously upon the bed of the stream and swept it out to sea.

Another great flood, in 1895, accomplished the same results, but it, finding a deep channel, spent its force in widening and deepening it the entire distance between Tampico and the mouth of the river, and restoring the sections which had become contracted there by the deposit of sediment in the floods which had occurred during the construction of the works.

With these facts—and similar ones from other works might be mentioned—let the reasons for such satisfactory results, given in discussing the writer's paper on the South Pass Jetties and the Galveston harbor plans, be stated by Mr. Eads:*

"THE JETTY SYSTEM EXPLAINED.

"It is known to all engineers familiar with harbor improvements, that the jetty system is a method of deepening and maintaining a channel across a shoal by such works as shall compel the water flowing over the shoal to pass through a narrower channel; but, as this paper will be read by some who are not familiar with harbor improvements, I will be pardoned for stating the following elementary principles which control such problems:

"*First.*—A current is caused by the fall of water from a higher to a lower level, which fall is indicated by the slope or inclination of the surface of the water.

* *Transactions*, Am. Soc. C. E., Vol. xv, p. 284, *et seq.*

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"*Second.*—Friction of the bed over which the water flows is the chief force opposed to the current.

"*Third.*—The velocity of the current will be increased by either increasing the slope of surface or by increasing the volume, or by lessening the friction.

"*Fourth.*—The friction increases as the width of the bed increases; that is to say, if the bed of the channel be twice as wide, the friction will be doubled; if its width be reduced one-half, the friction will be reduced one-half.

"*Fifth.*—The power of water to transport sand increases with the square of the velocity.

"As every grain of sand that lies upon the shoal is brought by the current and left there, because it could take it no further, it follows that we cannot hope to deepen the channel, except by increasing the current. This can be done in three ways, but in this case it is impossible to do it *at first*, except by increasing the slope of surface. After the current is *increased*, deepening commences, and as the contracted channel enlarges, the slope is gradually reduced to its former inclination. When this occurs the old rate of current would return, but the other two elements, namely, *increase of volume* and *diminished friction*, then continue the abnormal acceleration. As the deepening goes on a *reduction of slope* follows, and this finally reduces the velocity so much that deepening ceases. The slope results from the difference of the heights of the water in the Bay and the Gulf. *To facilitate* the flow from one to the other, by *leaving openings through the jetties*, tends to keep these heights nearer alike and the resulting slope between them must then *be less*, not greater. This is precisely what we do not want *at first*. * * * * * * * *

"Outlets Through the Jetties.

"As the reader may not at once perceive the mistake of leaving these openings to facilitate the flow into the bay, I will explain that, in a state of nature, the immense frictional surface over which the flood water has to pass in filling the bay retards it so much, that the tidal rise in the Bay at Galveston is probably 10% less than it is outside of the bar. On the other hand, the discharge of the ebb is retarded by the same cause, making the total rise and fall just inside of the harbor probably 20% less than it is at the same depth outside of the bar.

"The bottom of the channel is composed of separate grains of sand, without the slightest cohesion or bond. They were brought here by currents and left, because those currents, from some cause or other, became too feeble to carry them further. Now, the reader must remember, first, that a current depends upon *the slope of surface* of the water (not upon the slope of the bottom), and second, that the excavating or transporting power of the water depends upon the *velocity of the current*. This excavating power or *velocity of the current must be made greater* than it now is over the bar, or the channel cannot be permanently deepened by any artificial structures known to the science of engineering. And yet no engineer can increase this velocity *permanently*, as will soon appear. But the velocity *must*, nevertheless, be increased, or these masses of sand composing the bar cannot be *permanently* removed How can the velocity of a current be increased? In three ways. First, by increasing the *slope of surface*, which is the cause (or rather the exemplar of the cause) of the current. Second, by lessening the frictional resistance of the bed. Third, by increasing the volume

Mr. Corthell. or mass of the water. We cannot avail of these last two methods *at first*, but after we shall have *once increased* the velocity by permanent works, these two last means will then ultimately come to our aid. *At first* we have absolutely no power to increase the velocity of current but by *increasing the slope of surface.* These slopes are alternately towards the sea and from the sea, accordingly as the tide fills and empties the bay. They are by no means steep, as the average maximum tides are but a little over a foot high. The force of the present currents resulting from these low slopes cannot overcome the force of gravity in the grains of sand composing the bed of the channel. With the present slopes, volume and frictional resistance, the equilibrium between the *velocity* or transporting force of the current and the force of gravity in the sand is reached when the depth of 13 ft. occurs on the bar. If we should suddenly deepen the channel by dredging, it would be larger than Nature demands under the present conditions. The bay would then fill more easily, the slopes would be lower, the velocity less, and soon after the dredging ceased, the enfeebled current would drop its burden of sand in the enlargement, and restore the present depth. On the other hand, if we could suddenly drop a million tons of sand in the channel, and reduce the depth a few feet, what would occur? The bay would not fill so rapidly, and steeper slopes would occur in consequence. These would create greater current velocities, and the removal of the obstruction would be effected in a little while; and, with the recovery of the 13 ft., the bay would fill more easily, the slopes would diminish, and the former velocities of current would be restored. The slope results from the difference of level between the surfaces of the Gulf and the Bay. Any one can see that the more freely the water can flow from one to the other, the less difference will there be between the heights of their respective surfaces, and, consequently, the less will be the slope of surface through the channel between them, and the less will be the current velocity. This is certainly the very opposite of what *we must have* to produce deepening. We must have more rapid currents, and nothing but steeper slopes will produce them. Hence it is evident that *large openings*, and a freer communication with the bay through them, and over low, submerged jetties, are precisely what we do not want.

"Let us suppose that jetties were, at mean tide, suddenly placed across the bar, 3 000 ft. apart, and extended from 30 ft. depth inside to 30 ft. depth outside, and were so high and tight that all the water which passes in or out of the bay is compelled to pass through them. When the tide rises it will be impossible for the bay to fill as fast as before. The tide outside rising only to its normal height will produce a steeper slope through the jetty channel than existed in that locality before, because the surface of the bay must be lower, as it will have been deprived of a large part of its normal volume of the flood. This steeper slope will produce a more rapid current into the bay, over sands which are only quiescent under the present velocity. If this slope increases that velocity from 3 to 4 miles per hour, which is not an unreasonable supposition, the transporting power of the water will be increased from 9 units to 16 units. Wherever through this jetty channel the depth is least, there will the current be most rapid. Hence the inflow through it will have the effect of cutting down the high parts of the bottom first, and transporting these sands into the deeper places. In a few hours this whole process is reversed, and a steeper slope than before will exist in the opposite direction, and the sands of this contracted channel will be swept out to the sea, and will there be

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distributed by littoral currents or sea waves, out of the way of the outflow from the jetties. Of course, the greatest increase of slope will only occur at first, and at the highest and lowest periods of the tide; but *as the channel deepens the volume increases, and the ratio of friction to volume decreases*, hence lower slopes will then produce equally rapid currents. Therefore the bay will ultimately fill more and more quickly, and these abnormal currents will be thus toned down until the deepening ceases and a new condition of stable equilibrium, or what engineers call "a new regimen," is established between the maximum velocity of the current and the force of gravity in the sand. When this is reached it will be found that the tidal movement in the harbor conforms more nearly to the rise and fall in the Gulf, both in height and time, and that the slopes are *lower* than at present. Because the deepening of the channel will continue until the bay will again receive all of the water due to the difference in the tidal movement, and to the normal slopes of surface occurring between the alternating levels of bay and sea through this deep channel, and as the friction which now retards the entry and exit of the water will be greatly reduced through it, a correspondingly increased quantity of water will enter the bay.

"Any excessive increase of tide caused by winds will have the effect of permanently increasing the depth of this jetty channel, and of making it more capable of discharging such excessive quantities of water again. By such abnormal causes the channel will be so deepened that the currents from ordinary tides will not be sufficient to disturb its bottom. The greatest work of excavation is done when the velocities are greatest. The channel with high jetties extending out to deep water would get no accessions of sand, and the depth would be permanent. It must be apparent, from this explanation, that the object sought by these officers, namely, *facilitating the inflow of the tide* into the Bays at Galveston, Charleston, Sabine Pass, etc., by leaving openings through the jetties near the shore, is precisely the way *not to do* what they want to accomplish. Besides losing through them the most important agent for deepening the channel—the ebb tide—they will admit into the channel all of the sand which the sea waves can bring. *Submerged jetties* simply aggravate the evils caused by these openings. They really extend the openings over the entire length of the jetty. They prevent, by increased friction, the rapid inflow to fill the bay; they permit the loss of the ebb tide, and thus lessen the force that should be applied to deepen the channel; and they allow the waves to transport sand over them into the channel. Openings and submerged jetties are therefore an inexcusable violation of the very essence of the jetty system."

There are some other serious objections to the single-jetty plan at Aransas. There is no concentration of the ebb-tide flow to make and maintain a deep and wide channel. There may be a narrow, curved channel along the concave side of the work, but between that and the outlet at Mustang Island there is always likely to be a troublesome shoal due to the reversion point of the current previously referred to. And beyond, at the sea end of the curved jetty, there is always likely to be a shoal bar for want of a strong issuing current to sweep it away. Again, the channel throughout its whole length along the curved breakwater is exposed to the sudden and serious influx of sand at any time by southerly storms.

Mr. Corthell. In the case of the South Pass and Tampico Jetties, the bars in the sea are swept by currents passing across the ends of the jetties. The winds and storms from the southeast at the former, and the "Northers" at the latter, raise the surface of the water in the angle formed by the East and North Jetties and the shore line and produce a strong current around the windward jetty and across the fore shore of the sea bar, wearing it away and thus retarding its growth. There is no such force to rely upon at Aransas, for the wide opening between the land and the breakwater will prevent it.

This discussion is not upon a subject unfamiliar to the writer. He was the chief engineer of the project for two years during its inception, had charge of the matter when the charter was obtained from Congress in 1890, and made plans and estimates of the works, which consisted of two parallel, rectilinear jetties. He is confident, from his experience elsewhere and knowledge of the conditions at Aransas, that his plans, if carried out, would have given immediately a channel 26 ft. deep and at least 200 ft. wide at that depth, which could have been maintained easily by keeping up the works, and without resort to dredging.

It remains to call attention briefly to the closing paragraph of the author's appendix, in which, after making an erroneous statement about the effects of the recent floods at the Brazos, he says:

"Thus demonstrating the relative superiority of the principle of reaction by a single jetty, as applied at Aransas, to that of concentration by twin jetties at the Brazos River bar."

Let the writer say, first, there is no sort of comparison between the conditions at the two places. At Aransas there is simply a clean, salt-water, tidal connection between the Gulf of Mexico and a group of bays—Aransas Bay with 81½ square miles connected with Misquete, St. Charles, Copano and Corpus Christi Bays, which together have an area of 273½ square miles. At the Brazos, there is a great, turbulent, muddy river in times of flood, 1 000 miles long, flowing through a clayey country, and in floods vomiting its engorgement out upon the Gulf; with no tidal reservoir whatever, except what exists in a narrow river not over 400 ft. wide.

At Aransas, the normal depth on the bar was about 9 ft. At the Brazos, when the works were begun, there was a straggling channel of 5 ft., which had to be crossed by the East Jetty. The depth on the bar between the jetty lines was only 1.5 ft. Still, these works, though never completed or consolidated, due to financial reverses by the financiers of the project and for reasons outside of this project, deepened the bar and made a channel straight to sea, which, in 1896, had a depth of over 20 ft. at average flood tide, the plane of reference used.

The author states:

"Apropos of the severe floods in the basin of the Brazos River, Texas, in July, it was expected that the larger volume discharging

with greater velocity over the bar at its mouth between parallel jetties would materially improve the depth. On the contrary, the soundings show but 15 ft. in several places." Mr. Corthell.

The author was misinformed; for the writer communicated with the works and ascertained the following from the engineer and superintendent of the railroad and terminal:

"October 3d, 1899, VELASCO, TEXAS.

"Letter just received. First part rise deepened channel immediately outside jetties to 23 ft., mean low water. Latter part shoaled same place to 15 ft. in one small place, but deepened again to 16.5 ft. within two weeks; now 18 ft. Very marked improvement in river channel from Velasco to and through jetties. Never such depth water before; no harm to jetties. Bar entirely outside jetties. Now channel deeper and wider in front of jetties than ever.

"E. D. DORCHESTER."

The writer also communicated with Mr. William H. Coolidge, the attorney of the Reorganization Committee, in Boston, which has general charge of the property, and the following was received from him:

"My instructions from Velasco have been to the effect that almost without exception the flood removed bars, etc., so that there was a clear entrance drawing at least 18 ft., and with a very slight amount of work the depth would be 22 or 23 ft. With two or three very slight exceptions, the water was more than 20 ft. deep. The Government having taken charge of this property, I am told that a very few days of dredging will allow vessels to enter drawing 23 or 24 feet."

The writer's original report, made after one had been made by the Government Engineer to the effect that 10 ft. as a maximum might be maintained by jetties with a maintained channel of 6 ft. only; and that the $140 000, already expended by the Government without result, should not be supplemented by any additional amount, gave the opinion that a channel 20 ft. deep could be obtained and maintained by properly constructed jetties. He still believes this can be done, notwithstanding the unfortunate financial history of the work, the delays in construction and the inability of the company to complete the works at the time.

HENRY L. MARINDIN, M. Am. Soc. C. E. (by letter).—The method of improvement designed by Professor Haupt for Aransas Pass presents three prominent features, the most important of which, in the writer's estimation, is the "reaction principle" as shown in the curvature given to the breakwater. Mr. Marindin.

The principle is based upon the well-known effect produced by flowing water in the concave bend of a stream where the impingement of the current causes greater depth than in any other part of the cross-section, and, indeed, greater than in the straight reach.

The frequency with which running water flows in curves would seem to amount to a law of flowing streams, and this is nowhere illustrated better than in the case where the stream is free to carve out its own bed, as in the Lower Mississippi; there the regimen lies in cur-

Mr. Marindin. vature, and it is only when this curvature becomes excessive, and offers too much resistance to the flow, that during some period of flood stage the water takes a straight course—in the line of least resistance—across the more or less narrow neck of land separating it from the reach below—making what is known there as a "cut-off;" but this remedy is as much a violation of the regimen in one direction as the excessive curvature of the bend which caused it was in the opposite direction. The stream almost immediately proceeds to form another bend.

That it is not the mere velocity of current which induces erosion of the bottom of a channel must be acknowledged by witnessing so many instances where, in one case, a stronger current fails to produce erosion of the bottom, and in the other case, with the bottom composed of—to all appearance—similar material, a weaker current maintains greater corresponding depths.

The New York Narrows is offered by Professor Haupt as an illustration in point, and is an apt one so far as that a great depth of 100 ft. seems to be maintained by the comparatively low mean velocity of 2 ft. per second. There are instances where greater mean velocities fail to maintain 10% of the depth found in the Narrows.

The explanation offered by Professor Haupt for the great depth in New York Narrows is that a resultant force is produced by the flood stream flowing up on the bottom for eleven hours out of the twelve, indicating a huge vertical eddy. That may be the true explanation, but, in that connection, the writer may be permitted to ask if he has not misunderstood the report from which the statement is taken? Seven hours out of twelve would be more in accord with what has been observed in other parts of the harbor.

The flood current has been observed to flow up on the bottom, at the mouth of the Hudson, for 2½ hours before the ebb current had ceased to flow at the surface.

It has also been held that if both ebb and flood currents could be made to follow the same path or channel, although in opposite directions, the problem of improving the depth of outlets would be near a solution. This is seemingly the condition at New York Narrows.

The configuration of the shores at Aransas Pass seemed fitted for a "compound and reverse-curve breakwater." The position of the concave shore of Mustang Island made the convex part of the breakwater opposite to it possible, or, perhaps, better fitted than a straight jetty would have been, and, as the thalweg is found close to the shore, with ample depth, it only remained for this part of the breakwater to arrest any encroachment upon the channel from the north and east. Farther down, the reaction principle becomes operative until the deeper water is reached, beyond the bar.

It is not clear to the writer's mind wherein Professor Haupt has

Mr. Marindin.

provided for meeting the requirement stated in his seventh specification, viz.:

"It (the breakwater) should not promote the growth of the bar seaward by the deposit of material removed from the channel on the outer slope of the bar."

If material is being moved by storm waves, some of it will find its way past the outer end of the breakwater, and any material held in suspension or rolled along by the ebb on the bottom of the channel will be deposited in front of the outlet, no matter what form shall have been given to the end of the breakwater.

The writer does not know how much or how little sediment is brought down by the ebb out of the Pass, but if any amount is being carried, and a bar tends to form in front of the present curved end of the breakwater, an extension in continuation of the curve could not be continued for any great distance, for obvious reasons; and a reverse curve would be detrimental to the reaction theory, without transferring the reaction principle over a "crossing" to another concave breakwater located on the south side of the channel. Such a crossing means the formation of a middle ground, with decreased channel depth.

The second important feature in this improvement lies in having provided a wide gap at the shore end of the breakwater for the free passage of the flood tide, to fill the tidal reservoirs above the Pass, at a point which is not occupied by any considerable ebb stream, the strength of the ebb occupying, as it does, the concave shore of Mustang Island.

It is evident that where the working power of the ebb depends largely upon the drain of flood-tide waters, works of improvement should be so designed and constructed as to offer the least obstacle to the free access of the flood tide; under these conditions the building of continuous parallel or convergent jetties would be a mistake.

The third prominent feature is the location of the single curved breakwater on the side of the Pass from which may be expected the most violent movement of material, or that due to a littoral drift. The determination of this location should be based upon accurate and reliable information, previously obtained, as to the direction and strength of flood, the direction and volume of drifting sands or other material caused by prevailing winds and storm waves or by any littoral current. Professor Haupt disclaims having sought or secured any of these data, preferring the study of the topographic and hydrographic features shown on published charts, supplemented, as it must be, by the intuition of the engineer. This is well, if success follows it, but the writer is sure that the majority of engineers would prefer to have numerical data before them to mix with all the intuitive knowledge they may possess.

An analysis of the systems of parallel or convergent jetties and of Professor Haupt's system, as applied to Aransas Pass, shows them to

Mr. Marindin. be radically different. The application of the single "Reaction Breakwater" seems, from the results noted in the paper, to have been particularly successful in a very short time, notwithstanding the existence of an old rock jetty directly in its path and removed only in part. But the same system applied to South Pass or to South West Pass would prove a failure. In both of these cases the conservation of the energy of the current which obtains between their parallel shores and its maintenance as far as the bar, is necessary, not only to erode the bar, but to convey the millions of tons of solid matter, held in suspension and rolled along the bottom, far out into the deep water in front of the delta, where the rebuilding of the bar would be a very slow process, retarded by the action of any littoral current existing there. Parallel and continuous jetties are necessary to secure these results, and prevent the spilling of the currents laterally.

The same condition confronted the engineer at the mouth of the Brazos, and it may be said, parenthetically, that the present jetties in their incomplete state have secured within their limits as great depths as are found in the river a mile or two above the mouth.

The writer has endeavored to show in the foregoing remarks that, notwithstanding the success which has attended the single jetty, parallel jetties are justifiable and necessary under certain conditions.

Mr. Wisner. GEORGE Y. WISNER, M. Am. Soc. C. E. (by letter).—The peculiar nature of the reports made by the Board of Engineers on Aransas Pass, in November, 1897, and December, 1898, together with the fact that the expenditure of large appropriations will soon be required for the improvement of other harbors where the conditions are similar to those at Aransas Pass, make the paper presented by Professor Haupt very apropos at the present time.

The harbors on the Gulf Coast are of two distinct types, each of which requires radically different treatment in order to secure satisfactory results. The Mississippi River, the Brazos River and the Pánuco River, at Tampico, are all heavy silt-bearing streams during times of high water, and, if not controlled by tight jetties so as to maintain the full velocity of flow until discharged across the bar into the littoral current outside, a deposit of silt will occur and produce shoals instead of deepening the channel as generally expected. The strong currents of these rivers at flood stages are alone to be depended upon to produce scour in the channels, and all arrangements designed for securing tidal effect are not only useless, but tend to decrease the velocity of the silt-laden current, and thereby cause shoals by depositing silt.

At the entrances of tidal harbors, reversed conditions exist, and the erosive force required to deepen the channels must be obtained by accumulating vast quantities of water in the tidal reservoir, during the

flood stages of the tide, and concentrating the discharge along the axis of the required channel lines during ebb tide. Mr. Wisner.

Unfortunately for the success of many of the improvements attempted, the designers of the structures conceived the idea that works which had produced beneficial results at other harbors must necessarily be the proper remedy to apply. The result has been that millions of dollars have been expended on jetties which have been of absolutely no use, except to form breakwaters for the protection of dredged channels. One of the most serious difficulties which the designers of such works have apparently feared was that such strong tidal currents would be generated that the structures would be in constant danger of being destroyed, and, to avoid such a catastrophe, the jetties have invariably been located from 2 000 to 7 000 ft. apart.

Generally speaking, no deepening of channels has resulted from such construction, and whatever deeper channels now exist at these harbors have been secured by subsequent dredging.

At Galveston, with jetties 7 000 ft. apart, the dredged channel across the bar is from 500 to 1 000 ft. wide, and at Sabine Pass, where the jetties are 2 000 ft. apart, the dredged channel is only about 200 ft. wide, and shows no indication of increasing depth or width from tidal action. In spite of these repeated failures, the 1897 Board of Engineers not only endorsed the 1888 project for jetties 2 000 ft. apart at Aransas Pass, but condemned the unfinished curved jetty as worthless to the Government, and as an obstacle to future improvements, when their own published charts show beyond question that the results predicted for the enterprise would be realized at once upon the removal of the old curved jetty, which the predecessors of the Board located, unfortunately, on the wrong side of the Pass.

In the report of December, 1898, the Board recommends that the outer 1 000 ft. of the curved breakwater be removed, and that an extension be built on a line about 25° to the north of the present location, making an angle with the direction of flow which, it is safe to say, the currents would never follow. With a channel from 15 to 23 ft. deep, already obtained by the incomplete works now in place, it is hard to conceive why such structures should be removed, and be replaced by others which have been proven to be failures at other ports, where the conditions were similar, especially as the estimated cost is three times that necessary to obtain a 20-ft. channel by the completion of the works built by the Aransas Pass Harbor Company.

While it is true, as stated by the author, that parallel jetties are not well adapted for securing tidal scour at the entrance of tidal harbors, it is equally true that a single curved jetty at the mouth of a silt-bearing river would not only fail to produce a good entrance channel, but would not maintain it if obtained by dredging or other methods. The case mentioned, where the flood in the Brazos River

Mr. Wisner. failed to deepen the channel, is a direct proof of the principle involved, and was the result expected by those familiar with the situation.

The jetties at the mouth of the Brazos River have never been completed so as to maintain a full velocity of flow until the silt-laden water is discharged into the deep water of the littoral current outside the bar, and, therefore, in times of heavy floods a portion of the sediment is dropped at the point where the river current is slackened. The experience at the mouth of the Mississippi and Brazos Rivers indicates clearly that single jetties, no matter what their shape, would not maintain navigable channels at the entrances of those harbors.

To every careful investigator of the physical conditions at the entrances of Gulf harbors, there is plenty of evidence of the kind of remedy which should be applied to secure any reasonable improvements of the channels. The littoral current is a controlling force, which is certain to cause either success or failure, according to whether properly utilized or not.

At the mouths of silt-bearing streams, the suspended matter must be carried entirely from in front of the entrance before being deposited by a change in the velocity of the river current, and the shore drift must be prevented from entering the channel; two conditions which necessitate the construction of jetties on each side of the entrance, to deep water on the outside of the bar. The action of the littoral current in flowing past any system of jetties is to pile up the sand drift in the angle of the shore and jetty on the windward side, and produce an eddy on the lee side of the entrance.

On the Gulf Coast, the resultant of the littoral current is from the northeast to the southwest, and in the case of sediment-bearing rivers the eddy builds up immense shoals to the westward of the entrance, and at tidal harbors causes a reverse current along the shore to the westward of the jetties, which in connection with wave action may cause great damage by erosion.

This shore current, caused by the eddy to the westward of the jetties, has in certain instances led observers to believe that the littoral current was from the west.

At Galveston, the erosion of the city front from this cause has been so extensive that suits have been started in the Court of Claims to recover compensation for the damages caused by the construction of the jetties at the harbor entrance.

If the curved jetty designed for the improvement of Galveston Harbor, in 1883, by H. C. Ripley, M. Am. Soc. C. E., had been adopted, it would unquestionably have produced a deep channel across the bar with a saving of several million dollars in the cost of the improvement, and would have shifted the eddy caused by the littoral current far enough eastward to have caused but little erosion along the city front.

Mr. Wisner.

The construction of jetties at Aransas Pass will produce an eddy effect similar to that developed by the structures at the entrance of Galveston Harbor, and, if two jetties are built out to deep water, the west end of Mustang Island will be eroded, whereas, if only a single curved jetty be constructed on the north side of the channel, the center of the eddy will be shifted eastward, and the reverse current will combine with the ebb currents at the outer end of the channel. A short spur will be a necessity at the west side of the Pass to prevent the reverse current from the littoral eddy carrying sand into the channel. This spur should be built above high water as far out as the wreck *Mary*, and will tend to limit the action of the eddy and diminish erosion on the front of Mustang Island.

One of the most interesting instances of parallel jetties producing the opposite effect to that expected is that at Cumberland Sound, Ga., where the accumulation of drift between jetties 3 900 ft. apart became such that, in 1895, the channel shifted across the south jetty, and it became necessary to remove a portion of that jetty, to prevent the port of Fernandina from being completely closed.

It became evident, in 1890, that such a result was likely to be obtained, and O. M. Carter, M. Am. Soc. C. E., Captain, Corps of Engineers, U. S. A., the local engineer in charge of the improvement, recommended that the project for parallel jetties be abandoned, and that a single curved jetty be constructed on the north side of the entrance, to shut out the sand drift from the north and guide the tidal flow across the bar on the line best adapted for maintaining a channel with natural forces.

The deadly wisdom of the engineer board, whose consideration of a few hours outweighs the conclusions of the resident engineer who gives years of study to the conditions, proved fatal to the project.

There has been $1 787 000 expended on the work, which has in no way improved the entrance to the harbor. A continuous appropriation was made by Congress in 1896, to complete this project, of which over $1 500 000 remains unexpended.

It will be interesting to note how this vast amount of money is to be expended, especially as the engineer boards which have considered the problem at various times have practically admitted that the improvement was a failure, but did not have the courage to "advise any radical change in the general location of the jetties as originally proposed."

The conditions at Cumberland Sound are practically similar to those on the Gulf Coast, except that the rise of the tide is about three times that at Aransas Pass; and there is no reason why a single jetty would not produce as beneficial results as at the latter place, where an incomplete structure has deepened the channel from 8 to 18 ft. in a few months.

Mr. Wisner. Particular attention is called to the fact that the breakwater at Aransas Pass was constructed under the plans of the consulting engineers, without causing the bar to be pushed seaward the slightest measurable amount, an achievement which has never been accomplished at any other port on the Gulf Coast.

The action of erosive and bar-forming currents has been quite fully observed by the engineers who have had the actual charge of harbor construction on the Gulf Coast, and, while the results have not been published in the official reports, many of the facts have been discussed in the *Transactions* of this Society, and it is hoped that this paper will make the record still more complete.

So far as the writer is able to judge, these observations have established quite fully the following conditions and principles pertaining to harbors on the Gulf Coast.

1. The littoral current, during a season when effective, flows from the northeast to the southwest.

2. The sand moved along the coast by the littoral current, when stopped by jetties extending into the Gulf, accumulates in the angle formed by the east jetty with the shore; and the sediment carried into the Gulf by silt-bearing rivers is carried to the westward of the harbors, forming shoals extending seaward from the entrance of the jetty channels.

3. The littoral current flowing past the outer ends of jetties or breakwaters creates an eddy west of the entrance, which, at the mouths of sediment-bearing streams, builds up shoals in the quiet water at the center of the eddy; and at the entrances of tidal harbors causes reverse currents, which, in connection with wave action, erode the shore west of the structures.

4. A single jetty will neither make nor maintain a navigable channel at the mouth of a silt-bearing river.

5. Parallel jetties at the entrances of tidal harbors will not create navigable channels, but will generally maintain such a channel after having been obtained by dredging.

6. Where strong littoral currents exist during the season when sand movement occurs, a single curved jetty, properly designed with reference to the volume and velocity of flow through the pass, will create a navigable channel without aid from dredging, but it is preferable in all cases to aid the tidal action by dredging, not only to hasten results, but to insure a proper alignment of the channel.

Mr. Symons. THOMAS W. SYMONS, M. Am. Soc. C. E. (by letter).—The single jetty at Aransas Pass, or "reaction breakwater," as it is called by the author, is by no means a new thing in the engineering world, and, individually, it does not mark "a distinct advance in the resources of maritime engineers in the improvement of ocean bars," as stated by Professor Haupt. In fact, officers of the Corps of Engineers, U. S. A.,

have designed and have been building just such structures for years, and some of the most successful works of the Corps have been accomplished by adopting in the main the principles enunciated by Professor Haupt. Mr. Symons.

The writer believes sincerely that many harbor bars can be improved by a single jetty, or breakwater, if the name be preferred, to fully as great an extent, and in some cases to a much greater extent, than by parallel or converging jetties, and at enormously less cost, provided the single jetty be properly located to take advantage of all the natural forces at work. This belief is founded, not on theories only, but on actual experience in planning, locating, building and observing such works and their operation. The writer's experience on the Pacific Coast was so convincing as to this, that, in planning works for the improvement of Grays Harbor Bar, Wash., he designed a single jetty, and, Congress having made provision therefor, it is now being constructed under the supervision of Harry Taylor, M. Am. Soc. C. E., Captain, Corps of Engineers, U. S. A. This jetty has not only been described in official reports, but was the subject of a paper before this Society.* This Grays Harbor jetty is, in every essential respect, such a "reaction breakwater" as described in general terms by Professor Haupt.

The single jetty at Coos Bay, Ore., located and built under the writer's direction and supervision, 1890 to 1895, is a "reaction breakwater," and operates in practically the same manner as described by the author, in determining, deepening and maintaining a channel over the bar. This single jetty was located with a view to securing the maximum results in the shortest time and at the minimum of expense, and was eminently successful; a deep bar channel was developed and has been maintained in a permanent position ever since. A second jetty was planned to be built at Coos Bay, but as the first one has accomplished about all that was hoped from the two, it will probably be deemed unnecessary to build it. The great single jetty at the mouth of the Columbia River, which has accomplished so much for the commerce of Oregon, is a "reaction breakwater." So is the single jetty at San Diego, Cal.

These jetties fulfil nearly all the conditions laid down by Professor Haupt. Their principal point of variance is that they are not constructed on "compound and reverse curves," and have no gap or opening near the shore. In the localities mentioned these curves were not at all necessary, as there was no trouble in securing a deep channel inside the outer end of the jetty at either place. The bar, in advance of the jetty, was the real difficulty, and the channel across it was to be secured by directing the tidal currents upon it in a fixed location. In the instances mentioned this is accomplished just as well with the

* *Transactions*, Am. Soc. C. E., Vol. xxxvi, p. 109.

Mr. Symons. straight jetties as it could be with curved jetties. In fact, it was necessary in almost every instance to protect the jetties against undue erosion by groins built out on the channel sides. The construction of the "breakwater," so called, at Aransas Pass, is not made clear in the paper. It is apparently a brush and stone structure, a large part of which is founded on sand in 6 to 8 ft. of water. Alongside this and close up, the channel has been eroded to 18 or 20 ft. in depth, according to the map. This condition might well excite alarm for the safety of the structure. The possible undermining may, however, be guarded against by some construction not alluded to in the paper.

Along our Northern Pacific Coast there is an average tide of 6 to 7 ft., and the storms are much more frequent and severe than in the Gulf, all of which, of course, makes the problem of bar improvement vastly different from that at Aransas Pass.

Neither was there, at any of these Northern Pacific Coast harbors, any need to leave a gap near the shore to permit the tide to enter freely. The jetties as located and built leave the door open almost to its full width for the entrance of the tide, and there is practically no choking down of the flood tide, which, theoretically, there is with parallel or converging jetties. Besides, at these Northern Pacific Coast points there is a very practical objection to leaving a gap near the shore. The rough and tempestuous character of the waters prohibits absolutely the building of the structures from floating plant, and they must be built from tramways extended out from shore. If the tramway should be built and a gap left in the brush and stone jetty built from it, it is certain that the unprotected portion of the tramway would be undermined and destroyed.

Judging from the map, Fig. 2, this cutting has commenced in the gaps left in the Aransas Pass structure, and it is quite within the bounds of possibility that this may extend, and channels develop therefrom, to a degree which will lessen seriously the flow in the desired channel. If the flood enters freely through the gaps, the ebb will also run out freely, and it would seem the part of wisdom, where there is so little tide as at Aransas Pass, to control as much of it as possible. The sill, *G E*, Fig 1, would at least be necessary, in the writer's judgment.

In the case of Grays Harbor, the natural bar channel had an apparently unswerving tendency to move from north to south, keeping on with this movment until its extreme southerly position was reached, then breaking out again to the north and taking up its slow movement to the south. The jetty was located to interpose itself against this southerly movement with the hope and belief that the pressure to the south would continue, and that this pressure on one side opposed by the jetty on the other, and the inflowing and outflowing tidal currents, would produce the necessary agitating and scouring current-effects

necessary to determine and maintain a good deep channel and direct it permanently over the bar in the selected location. This work was planned in 1894-95, and is truly a "reaction breakwater" in all essential features, as described and named by Professor Haupt. Whether it will fulfil all that the writer hopes for it remains to be seen, and can only be determined in the future. Mr. Symons.

The great Columbia River jetty, planned in 1882, is also such a "reaction breakwater," interposed against the tendency of the bar channel to move to the southward.

At Coos Bay the movement of the bar channel was to the northward, and, consequently, the jetty was interposed against it on the north, and this northerly tendency and the reaction of the jetty have determined and maintained an excellent, deep-bar channel, permanent in location, ever since the jetty was carried out sufficiently far to make its influence felt. The writer is unable to believe that, in the great majority of cases, the curved trace, indicated by Professor Haupt as essential, is at all necessary, or the best. There may be cases, however, where such a trace best lends itself to the situation and control of the forces at work. Each particular case must be judged by itself.

While the writer is a believer in the single-jetty system, wherever applicable, he also believes that there are cases where one jetty would not be sufficient, and where parallel or converging jetties are necessary. A safe rule to adopt, and one by which the writer was governed in designing all the later works of harbor bar improvements which he has had in charge on the Pacific Coast, is to locate the first jetty to be built as if it were the only one to be built, and hope for the best. Under this plan, if it be found that the results obtained are not satisfactory, then other works, a second jetty, perhaps, can be added to better control the natural forces and direct the flowing waters. The writer's experience causes him to be very chary of predicting absolutely the results which can be obtained from any structure built to control the waters and sands of an ocean bar.

Professor Haupt and all concerned are to be congratulated on the results obtained at Aransas Pass. The very marked improvement in such a short time mentioned, however, naturally causes one to ask whether there is a certainty that it is permanent. This is mentioned because, in conducting harbor works on the Pacific Coast, very extraordinary results were obtained at times, but they were not permanent, and the real value of the works could only be determined by finding out the minimum depth and width of channel which could be depended upon under all circumstances. The author recognizes this uncertainty by his statement that "modifications, however, are always to be expected in depths due to variations in the natural forces." These modifications may in time, and probably will, render the entire

Mr. Symons. or partial closing of the gap in the jetty, and the construction of groins for its protection advisable and necessary.

If the author had extended his studies to the works of harbor improvement designed and carried on by the Corps of Engineers, U. S. A., on the Pacific Coast, his claim as to the epoch-making character of the Aransas Pass structure would probably have been greatly modified, in view of the fact that structures practically identical in character were designed, located and built years before it was thought of.

The correct principles of the single-jetty system appear to have been applied very successfully at Aransas Pass, and Professor Haupt has invented a new name for such a structure. The writer cannot, however, believe that the engineering world will accept the name "breakwater" as properly applicable to the structure at Aransas Pass. It is not designed to and does not perform the functions of a breakwater as ordinarily understood and defined. It is a training wall or directrix to the flowing waters, and the name jetty fits it much better than the name breakwater, and is more in accord with good usage and common understanding. A breakwater is from its very nature a reactionary structure, its object being to deaden the force of the waves, which roll in from ocean or lake, by interposing its weight and bulk in their path, reacting against them. To speak of a "reaction breakwater" is a redundancy.

Mr. Ripley. H. C. Ripley, M. Am. Soc. C. E. (by letter).—The adoption of the reaction or curved breakwater, for the improvement of a harbor entrance, is without doubt the greatest advance made in the science of river and harbor engineering that has ever been recorded in this country. For this reason this paper will be read with especial interest by those engaged in this branch of the profession.

The principles herein applied, however, are as universal and well established as the law of gravitation itself.

These principles are:

First.—That of reaction, by means of which, water, constrained to flow in a curve, excavates and maintains a greater cross-sectional area of channel than when flowing in a straight course, and the ratio of depth to section is always greater in a curved than in a straight channel, under otherwise similar conditions. For examples of these effects, see *Transactions*, Am. Soc. C. E., Vol. xxiii, page 153, where it is shown that for the Brazos River the average sectional area is 13½% greater in bends than in reaches, and the average maximum depth is 58% greater in bends than in reaches.

Second.—That of centrifugal force, by which the particles of flowing water tend to hug the concave side of a channel. This principle makes it possible, by means of a single curved structure, to concentrate the ebbing waters of a tidal harbor or the discharging water of a

river into a single channel of limited width, and convey it across the bar as effectively as can be done by means of two parallel jetties, where the aggregate length is double that of the single curved structure. Mr. Ripley.

Numerous examples of natural concentration of flowing water into channels of limited widths by this principle are to be found in the bays and sounds along the Atlantic and Gulf Coasts. A noted example is that of the channel of Galveston Harbor along the city front. This channel has a width of less than 1 000 ft. between the 6-ft. contours and a maximum depth of over 30 ft. This concentration of the tidal flow is due to the curved form of the shore line of Galveston Island, which brings into action the principle of centrifugal force.

These two are the cardinal principles involved in the application of the reaction or curved breakwater to the improvement of a harbor entrance. The writer thinks that no one will question their universality. Nor are these principles of recent discovery. They were recognized more than three-quarters of a century ago, by engineers having to do with harbor works.

The improvement of the entrance to the harbor of Swinemünde, Prussia, on the Baltic Sea, is an example of the successful application of these principles by means of a curved jetty extending from the shore on the east side of the entrance, across the bar, a distance of 3 900 ft., with a somewhat shorter angular jetty upon the west side of the entrance.

General Gillmore, in describing this work in 1881, wrote:*

"Several harbors on the Baltic Sea have been improved by means of jetties.

"Perhaps the most successful example of this method of improvement is shown at the entrance to the harbor of Swinemünde, the outport of the City of Stettin, an important commercial town of Prussia. * * *

"The west pier or jetty was designed to arrest the progress of the sand brought to the entrance by the littoral current, besides confining the currents of the outflowing waters. * * *

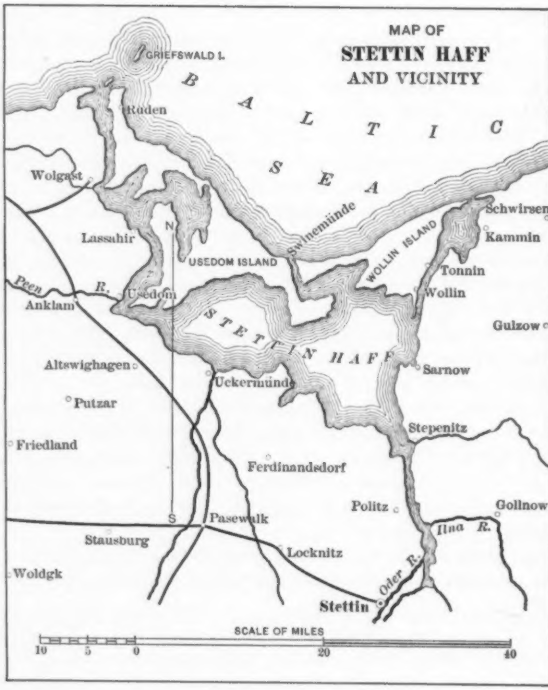
"The well-known fact that near concave banks, the currents of flowing water generally create and maintain a deep channel, induced the designer of the Swinemünde jetties to construct them on a curved plan, to secure ample depths, at least, on one side of the entrance channel. * * *

"The curved plan proved entirely successful, inasmuch as considerable depths were produced next to the east jetty; in fact, the opinion has been expressed that a more gentle curvature might have been better, as the depths in the concave bend are actually greater than needed, while on the opposite side, extensive shoals are found, necessarily reducing the width of the navigable channel and requiring the frequent use of dredging machines. * * *

"As a general result of this improvement, it is reported that the

* Report, Chief of Engineers, U. S. A., for 1881, p. 1060.

Mr. Ripley.



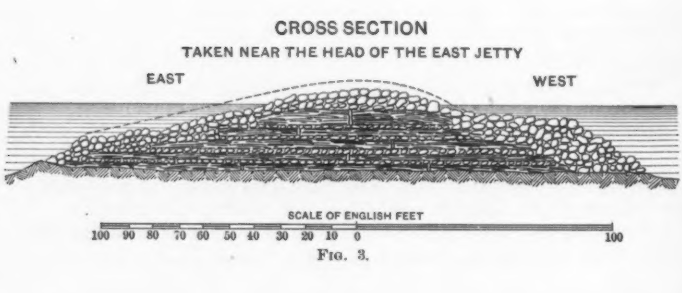


FIG. 3.

Mr. Ripley.

PLAN SHOWING
JETTIES OF THE HARBOR
OF SWINEMUENDE

Fig. 4.

Mr. Ripley. principal channel, in which the depths were only 7 to 7½ ft. before the works were begun, now has a navigable depth of more than 20 ft., which has been maintained for nearly half a century."

The plan of this work is shown in Figs. 3 and 4. While it is stated that the "curved plan proved entirely successful," the work as a whole has not been so, from the fact that the curved jetty was placed upon the lee side of the littoral drift, which encouraged its accumulation on the channel side of the curved jetty, with a resulting growth of the bar seaward, which will necessitate the ultimate extension of the works to prevent its overlapping the outer end of the jetty. Had the curved jetty been placed upon the windward side, the littoral drift would have accumulated next to the shore and its seaward growth would have been much slower.

About 16 years ago, the writer designed a detached curved breakwater for the improvement of the entrance to Galveston Harbor. Its location is shown by the heavy broken line in Fig. 5. The line of the North and South jetties as constructed is also shown. The condition of the bar and channels is that of the time of the survey in 1884. The present position of the shoalest part of the bar is outside of the line joining the outer ends of the jetties. At this point, the resultant littoral movement is to the southwest, as is indicated by the gentle curve of Bolivar Channel to the south as it approaches the bar.

The breakwater is placed on the windward side of the channel, and its curvature and position conform to the curvature and alignment of the natural channel, and as a resultant of all the forces acting upon it. The discharging water from the tidal basin meets this curve tangentially, and, upon the principle of centrifugal force, will be constrained to follow the curve throughout its length. The channel will therefore have no greater width than at the point of meeting the curve, but, on account of its curved form, somewhat greater depths will be developed and maintained than would be the case if the same movement of water were confined between parallel straight walls.

Its position on the windward side of the channel is such as to intercept the littoral drift and protect the channel from its degrading effects; and the littoral movement, being normal to the breakwater at its outer end, will oppose no dynamic resistance to the ebb discharge. The existence of this breakwater would exert the least opposition to the admission of flood water to the tidal basin consistent with the control of the ebb discharge, and it is probable that, with the development of the channel across the bar, an actual increase in the tidal prism would result.

This design was approved by the United States Engineer Officer then in charge of the work, and its adoption recommended. The results at Aransas Pass have demonstrated fully that, had its construction been authorized, there would have been saved to the Government,

Mr. Ripley.

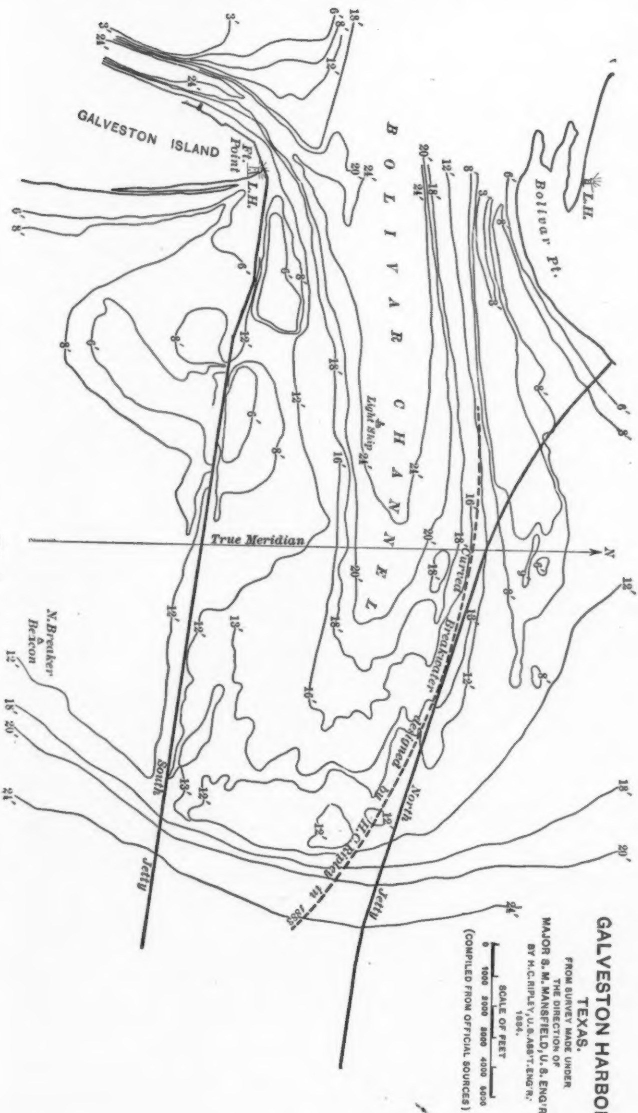


Fig. 5.

Mr. Ripley. in the improvement of this one harbor, not less than $4 000 000 in money and about four years in time.

There are many harbors on the Atlantic, Pacific and Gulf Coasts needing improvement, where the application of the reaction breakwater would be entirely feasible.

The curved jetty, involving the same cardinal principles as the reaction breakwater, would also be applicable at the mouths of many rivers, to the great saving in the cost of improvement.

After much study of the local conditions at the mouth of the Coatzacoalcos River, Mexico, the writer has proposed a single curved jetty for the improvement of the entrance to that river, with the estimated saving of about $1 000 000 in gold as compared with the estimated cost of two parallel jetties.

With the results at Aransas Pass, the writer is entirely confident that the improvement of the entrance to the Coatzacoalcos River would be entirely successful with the construction of the single curved jetty proposed.

Mr. Pitts. THOMAS D. PITTS, Jun. Am. Soc. C. E.—The speaker had the good fortune to be engaged as Assistant Engineer on the works at Aransas Pass for over two years, and, naturally, he has been much interested in the results.

From the depths maintained in the gorge, it would seem that the ebb-current velocity and tidal volume are sufficient to maintain a depth of 20 ft. or more on the bar, if properly controlled and directed. The speaker believes the results so far obtained show that the curved jetty on the north side of the channel, which was designed by the author, would be amply sufficient to control and direct the current, if completed.

In reports made to the Chief of Engineers, U. S. A., regarding contemplated improvements at Aransas Pass, it has been said that it would be very difficult to build and maintain a jetty there on account of the quicksand foundation. The curved jetty, built by the Aransas Pass Harbor Company, is founded on mattresses made of fascines of live oak and bay brush, the fascines being about 9 ins. in diameter and of varying length, according to the width of foundation desired. The mattress sinks into the sand somewhat when first laid and compresses considerably when fully ballasted, but it seems to last for an indefinite time. The foundation of the south jetty, built by the Government about 1885, was a similar mattress, and during Colonel Goodyear's blasting operations on the site of that jetty fragments of the mattress arose to the surface in considerable quantity. The wood of these fragments was quite sound, but the bark was partially decayed. A portion of the north jetty has now been in place for over 4 years, and no work of any kind has been done for more than 3 years. During that time there has been no evidence of any settlement of the

Mr. Pitts.

foundation, the small amount of subsidence noticed being amply accounted for by the consolidation of the stone in the body of the jetty, and by loss from the top due to heavy seas. In this last respect, the speaker has been surprised that the jetty has stood so well, in view of its exposed position, and the fact that no repairs whatever have been made.

Between August 1st and December 31st, 1895, a portion of the jetty 1 250 ft. long, *B—C* (Fig. 1), was completed to full size and section; a mattress was laid from *B* to *F*, 1 000 ft., and from *C* to *D*, 1 500 ft. The channel depths increased rapidly until, in November and December, a channel of 13 ft. could be traced across the bar. At about that time the foundation of the old Government jetty was uncovered, and the increase in depth ceased. Although the removal of a portion of the old foundation was urged repeatedly by the Consulting and Chief Engineers, no funds were provided for that purpose; but during the spring of 1896 the portion *C—D* of the jetty was raised to the level of high water, and the foundation was laid for a distance of 1 400 ft. from *D* toward *E*.

During August and September of the same year the mattress was extended to *E*, and the jetty was raised to low-tide level between *D* and *E*; but it was built of much less than full section, and two gaps of a total length of about 500 ft. were left. Until this last work was done between *D* and *E* the ebb discharge was practically not controlled at all, most of the flow passing to the northward of *D*, and the current across the bar was scarcely appreciable.

The condition of the jetty in the spring of 1896 was such that it caught and caused to be deposited on the bar the sand carried along the shore by the northerly current which prevails at that season. This current was of unusual strength and duration that year. In consequence of this sand deposit, the depth on the crest of the bar decreased so that there was only 5½ or 6 ft. of water in September. As soon, however, as the portion *D—E* of the jetty was partially completed as described, the current across the bar was noticeably increased, and the channel depths began to increase slowly. This increase was helped materially by the explosion of dynamite on the bar by Colonel Goodyear; chiefly by the destruction of a part of the foundation of the old Government jetty, but also partly by the softening of the whole bar, caused by the shocks of the explosions.

The increase in depth, which began in the fall of 1896, has been continuous since; being slower, or perhaps even ceasing entirely, during the spring and summer, and much more rapid during the winter, when severe "Northers" are of frequent occurrence. At such times the current is very rapid, surface velocities as high as 6½ and 7 ft. per second having been measured by means of float observations. These were probably not maximum velocities, as the engineering force had

Mr. Pitts. no facilities for making current observations during the times of greatest discharge.

The speaker's latest information regarding the depths on the bar is by letter from the keeper of the Life Saving Station at the Pass. From this he learns that there has been but little change in the channel during the past summer, but that the depths on the outer slope of the bar have increased somewhat. In the absence of a complete survey, it is not safe to assume too much; but the increase in depth on the outer slope would seem to show that the jetty is serving one of the purposes for which it was designed, *i. e.*, to prevent the advance of the bar seaward.

The south jetty, built by the Harbor Company in 1892, as mentioned by the author, was carried out some distance during the summer, and was apparently successful for a time. A deep channel was formed along the north side of the jetty, and there was some increase in the depth on the bar. The improvement was lost, however, as soon as the southerly littoral currents set in, in the fall. There was no improvement the next year, and a large part of the jetty had disappeared by the summer of 1895. This jetty was built of wooden caissons about 7 ft. in diameter, sunk in the sand and filled with sand and rock. A portion of this jetty is shown extending eastward from "Co. Wharf" on the map (Fig. 1). As will be seen, it did not in any way control the current, serving merely as a protection against the sand carried along the shore to the northward. In fact, the ebb current is deflected to the north by the revetment laid by the Government between "Co. Wharf" and Turtle Cove, and trends away from the shore line of Mustang Island before reaching the inshore end of the south or Nelson jetty.

The curved north jetty was designed by the author, not only to protect the channel from the inflow of sand from the north, which movement the speaker considers more important than that from the south, but also to control the current and compel it to scour out its own channel. The speaker does not believe that a straight jetty would serve the same purpose in this location, as suggested by Major Symons, for he thinks such a jetty would only deflect the current, without concentrating it, and that it would then spread out, fanwise, and lose its velocity and strength. With the curved jetty, on the contrary, the change of direction is gradual and continuous, and the conditions are similar to those in the bends of a rapid river, where it is well known that the greatest velocity and depth is found next the concave bank.

Major Symons also mentions four harbors on the Pacific Coast where single, straight jetties have been used with gratifying results. The similarity of the cases does not appear to the speaker, however. In one of these instances, the mouth of the Columbia River, there is

a very large fresh-water flow, and in all of them the tidal flow is many times as great as that at Aransas Pass. In all of these cases the entrance proper, between the headlands, is wide and deep, as shown by maps published in the Reports of the Chief of Engineers, U. S. A.; and there is a rise and fall of tide of 5 or 6 ft. The conditions are such that the bays doubtless fill completely at each tide, and the single jetty does not contract the entrance so as to diminish the tidal inflow. The depths and widths maintained in the gorges are far more than sufficient for any possible commercial needs; hence it is enough to control a part only of the ebb flow. Mr. Pitts.

At Aransas Pass, on the other hand, the entrance is naturally comparatively narrow, and the average rise of tide is only about 0.8 ft. It is therefore necessary, not only to control as large a part of the ebb flow as possible, but also to give the most ample opportunity for the flood tide to enter. The purpose of the opening left from *E* to *G* (Fig. 1), was to give a greater width of flood tide entrance, and the speaker believes that it is of material value for that purpose. It is true that a considerable quantity of water is lost through *G*—*E* during ebb discharge, but here again the water is thrown against the Mustang Island shore by centrifugal force, and the loss is limited to a surface one only. This is proven to the speaker's satisfaction by the fact that since September, 1896, when the foundation was completed to *E*, and the jetty from *D* to *E* was brought to a partially effective condition, there has been no tendency to scour in this opening; in fact, the depths have decreased somewhat.

The conditions at Tampico and at the mouth of the Brazos, where improvements have been made by means of parallel jetties, are radically different from those at Aransas Pass, on account of the large fresh-water flow at both of those places.

Mention has been made of the probability that shoaling would take place at the "cross-over." There would doubtless be some shoaling at that point, but the speaker does not think that the depth there would be the governing depth. He thinks the loss of water over the shoal to the southward would cause the governing depth to appear in the concavity of the jetty, and that it would not be less than 20 ft. under any circumstances, and probably much more. The latest chart available, from a survey made last winter by the United States Coast and Geodetic Survey, shows depths in the middle of the "cross-over" of about 17 ft. The speaker believes that the present bar acts as a dam to check the ebb current and to prevent scour on the inner slope, and that with the opening of a clear waterway of 20 ft. depth across the bar, the depths in the "cross-over" would be increased materially.

The fact that a current velocity which is abundantly sufficient to transport a given material will not always scour it from its bed was well shown at Aransas Pass. The material along this coast is a round-

Mr. Pitts. grained sand of light weight, which remains suspended in the water for a long time when once put in motion. Yet the speaker has seen this sand stand for days at a slope of 1 on 2 without perceptible erosion, notwithstanding the fact that a current of 3 to $3\frac{1}{2}$ ft. per second was impinging on it during every ebb tide. But the slightest shock, such as the explosion of a charge of dynamite under water in the vicinity, is enough to cause such a bank to slide. Any obstruction to the free flow of the water will cause eddies which produce rapid scour over a limited area. For this reason the speaker does not think that the stone from the foundation of the old Government jetty which was scattered by the dynamite explosions prevents scour. On the contrary, if that stone is as well scattered as he believes it to be, he thinks that it is a help rather than a hindrance, on account of the local scour produced.

The average range of the tides at Aransas Pass is less than 1 ft.; it is given on the Coast Survey charts as 0.7 or 0.8 ft. But there are times when the rise and fall are much greater. A long-continued southeast wind will raise the water 3 ft. or more above mean high water, and a succession of severe "Northers" will lower it as much below mean low tide. The speaker has seen the tide fall more than 3 ft. in less than six hours during a severe "Norther." As regards the character of the tidal curve; at the time of neap tides there is a well-marked diurnal rise and fall; but at spring tides there is but one pronounced tide in the 24 hours. At the time of spring tides, however, a short rise and fall frequently appears near the crest of the curve, and sometimes in the "valley." The foregoing is the general character of the curve, but it is by no means regular, the tides on this part of the coast being governed largely by the wind. The tide lags irregularly behind the moon's phase, and much more than on the open seacoast, but the speaker has no data at hand on this subject.

It is true that this work has stood for a comparatively short time only, as yet, but the speaker thinks that the results obtained since work on the jetty ceased, leaving it in an incomplete condition, are strong arguments in favor of the correctness of the theory on which it was designed.

Mr. Haupt. LEWIS M. HAUPT, M. Am. Soc. C. E. (by letter).—The writer feels under obligations to his colleagues for the interest and trouble they have taken in discussing this paper, each from his own standpoint and experience, it is true, but these side lights furnish an opportunity to illuminate the general problem.

General Review.—Some confusion has arisen from an attempt to measure results obtained elsewhere under totally different conditions; thus, instances are cited of the success of twin jetties where there is a large fluvial discharge at high velocities; cases which are not comparable with that under consideration, where there is no land drainage and a very small diurnal tide. Again, it is attepmted to compare a single

jetty projecting from the shore with the reaction breakwater which is purposely wholly detached therefrom; or, still further, linear work, having but a single function to perform, is cited as a precedent for curvilinear work designed to develop diverse agencies. Mr. Haupt.

Objections are also made to the use of the words "reaction breakwater" as being redundant, Major Symons not appearing to recognize the fact that the structure does break the waves from the north and northeast, forming a channel of quiet water in its lee and also producing a scour by the continuous reaction of the ebb currents along the concave front of the structure. These anticipated results, however, are so patent that no further space will be taken to reiterate them.

Mr. Corthell devotes considerable space to the impropriety of leaving an opening for the free admission of the flood tide, and quotes from Captain Eads the well-recognized principles applicable to half-tide or submerged jetties to sustain these views. As there is no question concerning their soundness and as the writer is on record in the papers referred to in his original paper, no time will be consumed in responding to this point which is also well covered by Mr. Marindin.

Mr. Corthell recognizes that the theory is "exceptional" and "peculiar," the work incomplete, and that, if correct, the cost will be only about one-third of that under present plans. Certainly, then, it is worthy of demonstration, which is all the writer has been seeking for years, and the testimony of Nature's agencies are now produced, as far as they have gone, to establish the correctness of their application at this difficult locality. This testimony does not seem to be refuted by any of the arguments submitted. The writer does not claim universal application of his plans to all conditions, as seems to be inferred from a few of the discussions; since each case is a special problem to be solved on its merits. Neither does he claim that a reaction is developed by a "convex bank." The function of the convex portion of the work is wholly distinct from the concave portion, but none the less important (as heretofore stated).

The unqualified statement that "it is not velocity * * *" that produces scour, is undoubtedly absurd, but it was not intended to be so used, as the context shows. It is a well-known physical fact that the mean velocity of a given stream, as generated by its surface slope, does produce remarkably different results under apparently similar conditions. The cases cited should suffice to illustrate the meaning, which was not to disparage either velocity or volume, without which no work could be done, but to direct attention to the tool, so to speak, whereby they may be applied to produce cutting. There is ample energy stored in the effluent at every bar, but, unless it is developed by some form of resisting medium and made to operate on the bottom, it glides to sea inoperative. The mean velocity is broken up and dis-

Mr. Haupt. tributed into complex bottom movements by the resisting breakwater.

A serious defect, so oft repeated in harbor works, in the writer's opinion, is the manner in which it is attempted to apply straight jetties to develop a channel; with the result that a deep hole is scoured out at the point of incidence of a current and the energy of the stream is dispersed by being reflected at an angle instead of being continuously supported across the bar. This is observable in many instances where twin jetties have been placed. It is the purpose of the curved breakwater to maintain a continuous reaction; which has been done, as shown by the results already secured. The currents are moulding their own channel, with a thalweg about 500 ft. from the axis of the work and parallel thereto.

Dublin harbor, which is regarded as one of the most successful instances of convergent jetty scour, was visited by the writer in 1889, and described in the paper on "Jetties for Harbor Improvements." Here the benefit was alleged to be due largely to the 600-ft. gap in the North wall, which admitted more water at flood than it emitted at ebb, thus changing the equilibrium between the heads of the jetties slightly in favor of the ebb. The dredging of the area within the jetties is not germane to the subject. From the relative positions of the jetties, shoaling is to be expected in this harbor.

Neither does the writer regard it as important to reopen the discussion on the resultant direction of the littoral drift at Aransas, which was brought out by Mr. Sweitzer's paper on the "Origin of the Gulf Stream,"* to which attention is directed. Suffice it to say that the accumulation of drift on every jetty built in the Gulf furnishes suggestive evidence as to the correctness of the location of the breakwater.

The writer does not wish to disparage any carefully observed data, but in these problems the elements are so varied in different parts of the same inlet and are changing so constantly (every hour almost) that even a very large number of simultaneous observations, extended over long periods, will not furnish as authentic a record as the chronographic resultant engraven on the plastic material moulded by the forces themselves. Careful comparative surveys are indispensable for this purpose, as well as measurements of the forces which have effected the results. A study of such charts, at various dates, is of more value than a few instrumental observations of velocities of currents, winds or tides, all of which, however, have a relative value. The writer's conclusions, as to the resultant direction of the littoral drift, were more fully set forth in previous publications. It is largely a resultant of the angle of wave approach, configuration of shore line, tides, wind, etc., all of which co-operate to produce the effect. At Aransas the consensus of opinion, as well as the efficiency of the work done, point to

* *Transactions*, Am. Soc. C. E., Vol. xl, 1898, p. 86.

the fact that the littoral drift is southwesterly. The small spur, 600 ft. long built in 1869, was a strong pointer. Mr. Haupt.

Twin Jetties at River Mouths.—The writer makes no issue as to the use of parallel jetties at the mouths of rivers, as his paper states. Twin jetties are but the logical outcome of Nature's laws in attempting to conduct an effluent stream over or through an obstructing medium. They constitute an aqueduct. To be most successful, they should confine the land discharge and exclude the tidal waters. The greater the preponderance of outflow, the better the result. But, in sedimentary streams, jetties serve merely to conduct the flow across the site of the original bar. When it reaches the sea, and the velocity is checked, the sediment is again dropped and the process of bar building and jetty extension must continue, unless there is a sufficiently strong littoral current to conduct the silt away from the outlet. If not, the depth may be maintained by dredging. Hence, as stated, every problem has its local features. A single curved jetty at a river mouth, however, may suffice to sustain the currents while crossing the bar, and prevent deposit, so long as they are reacted upon, causing their load to be thrust aside beyond the influence of the reaction and thus building up a mud or sand jetty at a suitable distance for navigation and automatically adjusted to the regimen of the stream, thus saving the price of one of the twin jetties.

This action is well illustrated in the results at Aransas, where the sand bar has been thrust aside and moulded without advancing seaward, making a counterpart to the breakwater, and aiding in confining the currents to their natural path. Other instances will be cited later.

Brazos Entrance.—As attention is called to the depths stated at the mouth of the Brazos as "erroneous" the writer begs to add that he hoped to find decidedly increased depths from the excessive fluvial discharge of last July's floods, and hence wrote to Texas to learn the results. A perfectly reliable authority replied, as stated in the paper, and on this condition a comparison was predicated. That it is substantially correct is confirmed by the letter of Mr. Dorchester, cited by Mr. Corthell, stating that it had shoaled to "15 ft." (It must have been at this date that the inquiry was reported.) "Subsequently deepened to 18 ft." The letter adds: "Bar entirely outside of jetties," etc. This, then, is still an incomplete work, and no final conclusions should be drawn. The writer has always had confidence in the twin jetties, as designed and partially built for this, the most promising river in Texas, for the application of this method. It is somewhat similar to Tampico, where Mr. Corthell's work has proven entirely successful. No "attack" is made on old methods, where properly applied, but it should be remembered that science is progressive, and in suggested improvements defects of existing methods may, with propriety, be pointed out, for the purpose of emphasizing

Mr. Haupt. and illustrating the particular applications of the new. This does not mean an unqualified condemnation of the old, and is in strict conformity with the law of evolution.

As early as November 19th, 1888, Mr. Corthell very kindly received the writer's publications and plans, returning them with the remark:

"They are all very interesting and you have certainly done an immense amount of work in collecting data relating to harbor phenomena. I cannot concur with you, however, in your improvement of tidal harbors, and cannot bring myself to believe that detached works such as you propose will obtain the depths required. * * * I have no occasion to design any works for exclusively tidal harbors."

This was before any results were obtained by any works of this character; but, for lack of space, further consideration of this valuable contribution must be deferred.

Mr. Marindin, physical hydrographer of the Coast Survey, recognizes the fact that streams, in carving out their channels in alluvium, ignore straight lines (which are those of the greatest slope between given points in a bend), and take to the curves where they scour to greater depths, as cited also by Mr. Ripley. This furnishes another answer to the point raised as to the velocity due to surface slope being the main factor in cutting channels, and brings out the reaction feature which has been so little utilized hitherto in engineering applications.

New York Bay.—In referring to the "Narrows" of New York Bay to illustrate the effect of "reaction *versus* velocity," as a cause for the observed effect, the writer quoted from memory impressions gleaned some 12 years before from the reading of a manuscript report by Professor Henry Mitchell, on the physics of this bay. This report was made in 1858–59, and revised in 1862, but was not published. The following extract therefrom is made by the courtesy of Professor Mitchell:

"The greatest depth of water was found at Station G (Fig. 6) in the Narrows, and here our lowest point of observation was 92 ft. from the surface. At this depth we found the flood current prevailing ten (10) hours out of the twelve (12) giving place to the ebb only at the most rapid fall of the tide. The flood stream, coursing along the bottom, reaches its maximum velocity near the time of high water; the highest rate observed being 1.82 miles per hour, a powerful scouring force! The greatest velocity of the ebb at the same point was observed to be 0.25 mile per hour, a force which according to the observations of Dubuat is incapable of overcoming the rolling friction of fine sand.

"The surface observations at this station indicate a very great preponderance of the *ebb current,* but it does not prevail so persistently as the flood in the lower stratum."

These resultants are more clearly illustrated by the diagram, Fig. 6, which accompanied this report, and which exhibit so forcibly the existence of this great vertical eddy swaying with the tide.

As the observations for velocity and duration were at a depth of 92 ft., while the bottom was 102 ft. below the surface, and the flood

resultant increases with the depth, it is probably nearer the truth to place its duration at 11 hours on the bottom, as stated in the paper. Mr. Haupt.

Is it safe to presume that a maximum velocity of 2.7 ft. per second, acting alone, will scour material from the bottom of a hole 102 ft. deep and will roll it up a slope to the level of the bed of the harbor, probably 60 or 70 ft. higher, when similar velocities will not disturb fine sand under 6 ft. of water on a down grade? Certainly, there must be some agency other than mere velocity to explain this phenomenon. The cautious engineer must take it into consideration, and may utilize it in designing his works.

Mr. Marindin is correct in his predictions as to possible extensions of the breakwater in case of extensive deposits beyond the end of the works, but as this is a drift and wave bar, with a practically clear

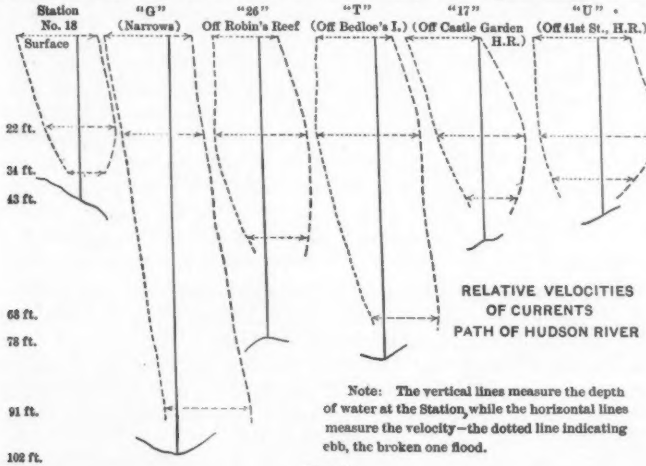


FIG. 6.

effluent (excepting perhaps during Northers), and as the reactionary effect of the currents is to displace material in a lateral rather than a longitudinal direction, rolling it to one side before reaching the outer end of the breakwater, and as this end curves so as to create confluent streams at certain stages of the tide to maintain the movement of whatever sand may be carried out, there has been no appreciable deposit at the outer end of the work, nor any advance seaward of the bar. The results speak for themselves. See discussion by Mr. Pitts.

In a sedimentary stream, a different curve and location should be adopted, to admit of greater possible extensions. That this is an important factor will be seen from the rapid movement of the Galveston bar, resulting from the failure to arrest the littoral drift by the construc-

Mr. Haupt. tion of the north jetty first; or still better, by the concave breakwater recommended by Mr. Ripley in 1883. The several efforts to secure deeper water at Aransas by a south jetty first also failed, because of the bar advance resulting in less depths. The effect is the same as that of placing a snow fence on the wrong side of a railroad cut.

The following is a statement showing the advances of the bar at Galveston, Texas, as indicated by the movement of the outer 18-ft. contour, and is taken from the blue prints of official surveys made on the dates indicated; measured from a "base" line joining station 220 + 18 on the North Jetty with the South Jetty beacon:

			From "base" to 18-ft. contour.
October	4th,	1894	650 ft.
"	23d,	"	750 "
December	"	"	1 150 "
March	3d,	1895	1 800 "
April	"	"	1 800 "
"	29th,	"	2 300 "
June	3d,	"	2 200 "
"	30th,	"	2 350 "
July	31st,	"	2 550 "
September	2d,	"	3 300 "
"	27th,	"	3 350 "

Depth in natural channel 16 ft. crossing south jetty. Over 60 000 ft. of jetty work in place in 1896. The increased depths in the channel were secured and maintained by dredging. The advance of the bar seaward during the year from October 4th, 1894, to September 27th, 1895, was, therefore, 2 700 ft. on a little more than half a mile, which was unprecedented. The bar, which was originally about 3 miles out, is now over 5, and still advancing.

The writer coincides entirely with Mr. Marindin's closing remarks as to the use of parallel jetties at the Brazos, while the case of the South or South West Pass is too large a problem to be embodied in this discussion, and must consequently be deferred.

Mr. Wisner distinguishes clearly the necessity of adapting the remedy to the conditions as to tidal or fluvial embouchement; also as to the need of admitting the full tidal prism at flood, and confining it during ebb to a local path, thus changing materially the conditions of equilibrium over that part of the bar intended for navigation, which cannot be done at tidal inlets by two tight jetties. The attempt to accomplish it has resulted in the waste of millions of dollars and constant charges for maintenance by sluicing or dredging.

While twin jetties have been successful at the mouths of rivers having no estuaries, the writer does not think, as already intimated,

Mr. Haupt.

that a single well-built and properly placed reaction jetty would not produce quite as good results where there is a resultant littoral current to remove the débris and prevent the advance of the bar. In fact, he is familiar with several very successful precedents. To cite only one, a single curved jetty of 3 000 meters radius has deepened its bar four-fold, where "for centuries before the struggle against the bar consisted in prolonging simultaneously two jetties from either bank of the river, leaving between them a distance of about 500 ft. But the sands outran the heads of the jetties, the flats were extended and the bar reformed. * * * Now (1889),* the bar has actually vanished," and the tonnage has increased enormously. From this instance it would appear that a single concave curved breakwater at the mouth of a river may produce the relief desired at much less cost than by two jetties, and hence becomes the better solution. This is also confirmed by the experience at the mouth of the Columbia River in Oregon, which was begun by Major Powell, Corps of Engineers, U. S. A., in 1885, at an estimated cost of $3 710 000 for a half-tide jetty, to be supplemented by raising it to high water, "or by building a short work on Peacock Spit for an increase of contraction."† The second jetty was not built, as it was found necessary to raise the first to high water to intercept the sand successfully, and this, with the drainage of the Columbia River, served to produce sufficient depth.

Experience, thus far, at Aransas does not indicate that the short spur on the west side to the wreck of the *Mary* will ever be required, since the currents, even in the present condition of the work, are abundantly able to protect the channel from the eddy action referred to, and the fact that the breakwater is detached from shore modifies this action greatly. The currents have built their own protecting barrier of sand without cost to anyone or injury to navigation.

The jetties at Galveston, Cumberland Sound and other points are placed too far apart to co-act in producing scour. This results from the desire to admit as much of the flood tide as possible and therefore lessens greatly the concentration at ebb, and, since both flood and ebb movements follow the same path through the same area of cross-section, there is no beneficial resultant, and dredging becomes a necessity, while the bar moves seaward at a more rapid rate than before. This is not similar to the flood and ebb in a river where there is a resultant.

A few words as to Cumberland Sound, by way of illustration. The plan of 1879, as revised in 1891, consisted of two low jetties of stone, having their outer ends parallel and about 3 900 ft. apart. Work was commenced in 1881. The expenditure to July 1st, 1890, amounted to $479 550.28. The results were "considerable shoaling." The channel

* *Mémoire*, Société des Ingénieurs Civils, etc.

† In closing the discussion on Grays Harbor in 1896 it was stated that the writer was in error on the proposition to use two jetties at the mouth of the Columbia, and there was no opportunity to state the authority, which is, therefore, quoted as above.

Mr. Haupt. divided, the southerly one having "13 ft. at mean low water the same as reported last year."*

In reporting on this site, in 1879, General Gillmore said "the draught of water that can be carried over the Fernandina Bar (Cumberland Sound) varies from 11 to 12½ ft. at mean low tide, with exceptional depths 1 ft. greater, and a mean tide of about 6 ft." Estimated cost $2 071 023 to "give a low-water depth in the new channel of 20 to 21 ft."

The present depths between jetties, as shown by the chart of 1898† is less than 6 ft., and there has been appropriated $1 787 500. Hence it follows that for each of the, say, 6 ft. of depth lost between the jetties the cost has been about $298 000, while it was estimated originally that each foot of depth gained should have cost (estimating on 8 ft.) $260 000, making a difference of $558 000 per foot between the predictions and realities. The actual increase obtained by dredging south of the jetties, as reported, was 2 ft., making the cost per foot $893 750 for a temporary result secured after about nineteen years of effort.‡

On June 30th, 1897, the crossing on the bar half a mile south of the jetties gave "depths of only about 13 ft." Captain Carter then reported that the project has "proved unsuccessful for the sole reason that funds have not been supplied regularly and in adequate amounts," whereas, in the writer's opinion, the location and design of the jetties was largely responsible.

In submiting his revised plan, dated October 8th, 1890, Captain Carter recommended a concave wall on the north side of the channel, thus intending to dispense with the southerly jetty. This, he says, would involve "the removal of the central portion of the South Jetty, which is improperly located." For this plan, including the removal of a portion of the South Jetty, the estimate was $1 108 000, while for the original plan the estimate was nearly double; yet, after revision,

"the Board, after consideration of all the conditions, does not advise any radical change in the general direction of the jetties as originally proposed. It does not think that a single jetty on the north side of the channel, curving gently to the south, would secure the deep water needed, but is of opinion that two jetties will be necessary," etc.

In view of this opinion it may be instructive to add that the last report available (surveys of June, 1898) shows only 5.9 ft. between the jetties, instead of 13 ft., while the present channel crosses the south one, the outer end of which serves to protect a crossing which has been opened on the bar by dredging under its lee; so that the two jetties are absolutely useless for concentration and scour, serving merely as sand arresters, and are serious obstructions to the currents which they cross.

* Report, Chief of Engineers, U. S. A., 1891, p. 1560, *et seq.*

† Report, Chief of Engineers, U. S. A., 1898, p. 1326.

‡ The cost of the dredging is not stated, but as it is not permanent and should be capitalized, say, at 3%, it will probably not differ greatly from $25 000, the interest on $833 333.

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The project was revised again in 1895, and estimated to cost $2 350 000; and in 1897 it was recommended that dredging be commenced in accordance with the adopted project, $50 000 being appropriated for the purpose.* Work on the jetties, by the Atlantic Contracting Company, was suspended on October 9th, 1897. The dredge boat could not work between the jetties because of the shallow depth, so it worked south of the South Jetty. A clam-shell dredge was also put to work to open a channel through the South Jetty to a depth of about 15 ft. The next season a channel of 17 ft. depth was opened by dredging the bar up to the jetty, but it shoaled up during the following months. The results secured, therefore, are wholly due to dredging, and are temporary in character.

It remains to connect the recommendations of Captain Carter, of a single curved wall or breakwater in October, 1890, and its rejection by the Board, with the plans of the writer, by stating that these plans were mailed to Captain Carter, then in charge of Cumberland Sound, at his request, on May 5th, 1888, followed by the discussion of the adverse report of the Board on the writer's plans,† March 28th, 1889, yet, after a careful study of the local conditions, in the light of the facts therein contained, he (Carter), without the knowledge or advice of the writer, concluded to recommend their adaptation to his problem, but which the Board declined to endorse, with the results as above. It is probably this action which Mr. Wisner characterizes as "the deadly wisdom of the Engineer Board * * * which proved fatal to the project."

The opening paragraph of Major Symons' contribution creates the impression that he is unable to distinguish, as was also the Board of Engineers of 1889, between a reaction breakwater, placed on the crest of the bar and having a specific form and position, and an ordinary jetty having its root on shore and projecting as a groin into the sea; but the distinction is radical and vital, and it would seem that the mere assertion of the lack of originality, as an opinion, should have but little weight when not supported by reference to the alleged precedents, which neither he nor the Board have seen fit to quote. Neither has the writer, after diligent search through an extensive field of harbor literature, been able to discover any anticipation, even approximate, save that of Major Ripley as proposed, but never built, at Galveston.

In view of the claims made in this part of the discussion as to the single-jetty work done on the Pacific Coast by Major Symons, the writer feels constrained to state that it is believed all of his work was planned subsequent to the publication of the plans and the discussions provoked thereby.

* Report, Chief of Engineers, U. S. A., 1898, page 1324.

† "Discussion of the Dynamic Action of the Ocean in Building Bars, being a reply to the Report of the Board of Engineers, U. S. A.," *Proceedings*, Am. Phil. Soc., March, 1899.

Mr. Haupt. The instance of Grays Harbor cited was not discussed until about nine years after the writer's earlier papers appeared, and if "it is in every essential respect such a reaction breakwater as described," as stated by Major Symons, then it does not furnish a precedent, but rather a remarkable confirmation of the soundness of the writer's plans, and becomes as well an infringement upon his property rights to his idea.

As the writer stated his views in the discussion of 1896, it will suffice to refer to the *Transactions** of this Society in reply as to the expectations; but the subsequent work done there will serve to show how little actual resemblance there is to the reaction breakwater, for the jetty is built on the south side, is connected with the shore, is straight for a considerable distance, whence it curves away from the channel (or is convex, not concave), is intended to be 3½ miles long, is estimated to cost $1 000 000 and is expected to produce 24-ft. depths. In other words, it is not solely a tidal harbor; no provision is made for changing the equilibrium of ebb and flood or for the development and utilization of the reaction of the ebb currents, while only a partial barrier is opposed to littoral drift by this structure, which is so different in plan and location from that under consideration.

The ruling depth shown in the chart of 1896 was 13 ft., and that in the report of 1898 remains the same, while the proposed jetty crosses the channel. It would therefore seem to be a repetition of the unfortunate Government experience at Aransas Pass in 1885, excepting that the outer end of the jetty is convex to the channel instead of concave, which is so much the worse for the channel. At all events, since the jetty is not yet completed and no results are available, it does not seem to bear at all on the question of a precedent as to tidal scour resulting therefrom. This is confirmed by the admission that, after all, double jetties may be required there, and they are estimated to cost $2 500 000.†

The next reference given, as anticipating the writer's plans, is the single jetty at Coos Bay, located and built under the writer's direction and supervision, 1890 to 1895, which is a "reaction breakwater," etc. Here, again, there is a lapsus in the chronology, since the plans of the writer were published in 1887–88. How far, therefore, Coos Bay may be an anticipation or even an embodiment of those principles may be seen by a brief reference to its history.

The annual report of Captain Powell, 1886, says:

"The plan is to build a half-tide jetty or deflecting dike about 2 400 ft. long, * * * inside of the entrance, on a slightly curved line toward Coos Head. * * *"

The amount expended is $128 259.25. The original estimate of cost is $600 000.

* *Transactions*, Am. Soc. C. E., Vol. xxxvi, 1896, p. 109.

† Discussion by Mr. Allardt, *Transactions*, Am. Soc. C. E., Vol. xxxvi, 1896.

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This is, therefore, only a wing dam built on the bank of the stream inside of the bar. It was soon "submerged" and injured and "jetty operations were last closed in December, 1884."

At this point there is a rocky headland on the south and a sand spit on the north. It is said that "about once in 5 years the outflow sought a shorter line by a breach through the north spit," etc. Depth at low water, 14 ft. The report of 1898, made by Major Fisk, Corps of Engineers, U. S. A., says:*

"The present approved project† provides for constructing two, high-tide, rubble-stone jetties to obtain and maintain at the entrance to the bay a low-water bar depth of at least 20 ft. The North Jetty to be 9 600 ft. long and the South Jetty 4 200 ft. long."

It also provides for sand fences on the north spit. Estimated cost, $2 466 412.20, independent of the $213 750 expended on the original project. "All operations have been confined to the North Jetty. * * *" The channel was well south of the jetty, but it has since moved gradually back to its normal position nearly parallel to the line of the jetty.

The map accompanying the report of 1891 ‡ shows the plan to consist of two jetties, the north one extending from the sand spit southwardly, to canalize the effluent, then curving in a long sweep, convex to the channel and extending seaward in a straight, westerly line parallel to the companion jetty as proposed from Coos Head and 1 500 ft. distant therefrom. This chart bears the signature of Captain Symons, and is dated 1891. It contains the following legend:

"To construct two brush and stone jetties converging upon and crossing the crest of the bar at a distance apart of 1 500 ft. * * *"

Mean tide, 5 ft. 6 ins. Soundings in feet show a minimum depth of 19 ft., so that whatever results were secured at Coos Bay at that date were due solely to the renewal and extension of the Powell inner jetty of 1879, for which the twin jetties were substituted by the Board of 1889, and which were not in existence in 1891. Naturally, under this project, the proper order of procedure would be to build the North Jetty first, as was done, thus controlling the movements of the spit and protecting the channel; and this work, with the rocky headland, should suffice, if well placed, to maintain the requisite depth, with the assistance of the ample tide and rapid land drainage, so characteristic of the Pacific Coast. By this date, probably over a mile of this jetty has been completed, and to June 30th, 1896, the sum of $738 750 was appropriated, but the gain in depth resulting therefrom is not stated in this discussion. The Report of 1898 states, however, "During the past year the channel over the bar had a depth ranging

* Report, Chief of Engineers, U. S. A., for 1898, p. 2963.

† See Report, Board of Engineers, Officers, 1890, pp. 2936-65.

‡ Part v, facing page 3162.

Mr. Haupt. from 18 to 22 ft. at mean low water," while the Report of 1892 also states that at various times there were depths of 18 ft., and, when the channel was 1 000 ft. further south, there were 27 ft. at low water across the bar. As there were 19 ft. of water shown on the chart of 1891 before the North Jetty was started, it is difficult, therefore, to see wherein it has materially aided in deepening the channel by natural scour, even with the large volume of tidal and fluvial waters available.

In short, the North Jetty as built at Coos Bay is in no sense a reaction breakwater, such as is partially completed at Aransas Pass, and the writer fails to understand how a structure which did not exist in 1891 when the depths shown prior thereto varied from 19 to 27 ft. can be said to have developed a deep bar channel when the reported depths at date, 1898, were 18 to 22 ft.

Neither is the jetty at the mouth of the Columbia a "reaction breakwater," according to the writer's views and purposes. It is merely a sand barrier serving to arrest the littoral drift and thus reducing the work to be done by the ebb stream; but, as its outer end curves away from the channel, its reactionary effects are lost and its efficiency reduced. Moreover, the physical conditions as to its being exclusively tidal are wholly dissimilar.

The allusion to San Diego appears to be equally unfortunate as an attempt to establish a precedent. In 1891, it was reported that "The approved project contemplates the construction of a jetty about 7 500 ft. long on Zuninga Shoals, so as to give a depth of 26 ft. at mean low water over the bar, the present depth at the same stage being 21 feet."*

There was already another but crooked channel, having 36-ft. depths, and it was proposed to create a new one in a different place by building a breakwater from Coronado Island to cut off the drift and to deepen to "24 ft." by dredging.

Work on the jetty was commenced in September, 1893, and the latest report at hand, 1898, states:

"No work was done during the fiscal year ending June, 1898. There is now an available depth of 21 ft. at mean low tide. * * * Total cost to June 30th, 1898, $289 741.35."

Hence there is no improvement in depth and no similarity of conditions to those at Aransas, while the entire project was executed subsequent to 1887.

On this basis this analysis might be extended indefinitely, but the writer believes that his statement, as made, remains unshaken; that the incomplete work at Aransas marks "a distinct advance in the resources of maritime engineers"; and he appreciates the force of the concession made by Major Symons in his opening paragraph that "some of the most successful works of the Corps have been accomplished by adopting in the main the principles enunciated by Professor Haupt,"

* Report, Chief of Engineers, U. S. A., for 1891, p. 2961.

even though the references cited do not appear to show very great improvements, if any, nor an adaptation, to any considerable extent, of the principles. But the intentions are unquestionably good, even though the principles may not have been correctly applied. Mr. Haupt.

In reference to the alleged precedents on the North Pacific Coast it should be noted, moreover, that Major Symons states that the movement of the channel at Coos Bay was to the "Northward," and hence the jetty was placed on the north or far side thereof, while at Grays Harbor the "channel had an unswerving tendency to move from north to south, etc." "The jetty was located to interpose itself against this southerly movement with the hope and belief that the pressure to the south would continue." This jetty was, therefore, placed on the far or south side of the channel. Thus, in both instances, they are directly opposed to the location as adopted at Aransas, where the jetty was purposely placed between and not beyond the resultant littoral and the channel, with such decidedly beneficial results, while, in all other cases of Government work on the Gulf, the first jetty was constructed on the far side of the natural channels, with disastrous results and greatly increased cost.* This erroneous location, on the far side, increases the work of the ebb instead of diminishing it, by permitting the littoral forces to carry material into the channel instead of arresting it on the near side, which is a fundamental condition of the design and location, which does not appear to have been fully comprehended or applied by the engineers of those works. Yet the writer has laid it down as the first desideratum, viz., to keep the littoral drift from entering the channel. A jetty on the far side does not meet this condition, and is therefore no anticipation of either the principle or its application.

While claiming similarity, Major Symons goes on to show radical differences, and the reasons therefor. He calls attention to straight jetties built ostensibly to cause erosion and yet having "groins on the channel side to protect them from undue erosion," thus destroying in large part their efficiency. That the work at Aransas has withstood storms for over three years without material subsidence is a sufficient answer to the query as to how it was built. That was one of the purposes of its plan, and with the submerged Government jetty reflecting the currents against its face it may well excite surprise that it has not been undermined long ago. The gaps are undoubtedly a serious menace to the work. They were left by the Harbor Company and were beyond the control of the engineers, yet, notwithstanding the losses of water and entrance of sand through them, the deepening of the channel has been continuous. To build the sill *G E*, as suggested by the Board of Engineers, and endorsed by Major Symons, would, to

* *Vide* discussions on Sabine Pass, Galveston, etc., in *Journal*, Franklin Institute, and in *Proceedings*, Am. Soc. C. E.

Mr. Haupt. a large extent, destroy the preponderance of the ebb movements which the writer desired to create; cause the groin to fill with sand, the shore line to extend seaward, to deliver its drift in front of the channel, and re-create the bar in front of the breakwater. All of which are to be avoided as injurious.

The opening at the shore end was commended by H. L. Marindin, M. Am. Soc. C. E., Assistant on the Coast Survey, as early as December 26th, 1889, when he reported to the Superintendent, as follows:

"One of the good features in Professor Haupt's theory is his objection to the closure of beach or flood channels. This is a strong point in his system and it is in contradistinction to the plans generally submitted by engineers."

This strong point the Board's plan would destroy. Mr. Marindin evidently has seen no reason to modify this opinion since. In none of the cases cited by Major Symons is this salient feature present, neither is the concavity for reaction; nor the peculiar combination of curves intended to reinforce and protect the work from wave action on the one side or too great erosion on the other.

The writer does not claim that the combination, as partly built at Aransas, is a panacea for all ills nor that all its features are at all times "essential," but for tidal inlets he does believe that the results, under peculiarly adverse circumstances, stand unrivalled in the history of maritime works, and that its intelligent application will effect far more rapid and permanent results at much less cost than twin jetties as now applied.

If the writer comprehends clearly the drift of the argument submitted by Major Ripley it is to show that the principles embodied in the peculiar structure built at Aransas Pass are not novel, but, as the writer has made no claim to having discovered new laws or applied new principles, he need make no other comment than to call attention to the new embodiment of these old principles in the breakwater which was located here with the assistance of Messrs. Ripley and Wisner.

In the ancient harbor of Swinemünde referred to, however, there will be found some material differences between the curved jetties in pairs at the mouths of sounds having large fluvial water compartments with several inlets and the case in point. The extract from General Gillmore's report of 1881 shows two jetties, both curved and rooted to the coast line, which it is asserted were "entirely successful," yet "requiring the frequent use of dredging machines." This, certainly, is a very different construction and result from that at Aransas, where there has been a marked increase from a single detached structure, without dredging, and which has been constantly deepening.

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The progressive improvement at Aransas, due to scour alone, may be seen from the following surveys and reports:

	Depth on Bar. M. L. W.
Survey of December 10th, 1896	6.5 ft.
" " February 2d, 1897	8.0 "
Old jetty breached (500 ft. in length) between December, 1896, and May, 1897:	
Survey of June 8th, 1897	8.75 "
" " November 5th, 1897	9.25 "
Reconnaissance, February 5th, 1898	10.00 "
Pilots reported, June 15th, 1898	11.00 "
" " August 29th, 1898	12.00 "
" " (by telegram) January 4th, 1899	13.3 "
United States Coast Survey, February 11th, 1899	15.0 "

These are the depths entirely across the bar, with depths on both sides of the old Government obstruction of over 22 ft.

The writer would be pleased to go more fully into the details of the harbor works on the Baltic, and make public some very interesting old charts, covering several centuries, secured during his visit to these ports, but the length of this discussion is already too great. Suffice it to submit a few excerpts from the report of Assistant Davidson, in 1875, showing the local conditions at Swinemünde. From this it appears that the longer mole is on the side to "windward" as regards the drift and not to leeward; there are also the usual phenomena attending jetties in pairs, but the channel is more permanent and more easily maintained because of its curvature being concave to the channel.

*Swinemünde on the Baltic.**—The Sound has three outlets. There is no tide in the Baltic save that created by winds. In 1828, the depth was 6 ft. There is a constant current out from Stettiner Sound, supplied by fresh water from the rivers Oder, Ihna and Ucker. The channel at 24 ft. depth is not quite 175 yds. (525 ft.) wide. Two ocean steamers can pass without difficulty.

"The artificial channel is composed of two nearly parallel moles of unequal length * * * curving well to the westward. The outer mole is 115° of a circle having only 2 000 yds. (6 000 ft.) radius, and for two miles the deep water scours directly under its wall."

The west pier has no parapet. The gales of 1874 and 1875 carried away 250 ft. of the east parapet bodily into the channel. The piers have been prolonged several times as the deposits have taken place. The beach has made 1 050 yds. seaward. What littoral drift there is seems to prevail from the eastward, and the deposit on the westward is partly from the Sound and partly from the littoral drift, but the increased depth is not wholly due to the piers, but in part to the con-

* Notes from the Report of George Davidson, Assistant, U. S. Coast Survey, 1875, p. 300.

Mr. Haupt. stant use of a small dredger. The cost is quite moderate and the results the most favorable yet seen upon a coast subject to heavy gales.

In conclusion, therefore, the writer is unable to find, in the cases cited, a solitary instance of a tidal entrance where there is a detached, concave, single, reaction breakwater, which has effected so great scour, in so short a time, with no assistance from dredging, in the face of an almost fatal obstruction, and at so little cost. If such a precedent is known to exist he would be grateful to learn of its location.

In view of the results already attained by this reaction breakwater and of the efforts which have been made, first, to prevent its introduction; and, subsequently, to so modify it as to destroy its practicability, he believes that the work should be carried to completion upon the original plan as a contribution to science and a demonstration of its ultimate efficiency. It is self evident that if equally good results can be obtained by so inexpensive a work, without dredging, many millions of dollars may be saved, while the barriers which have so long obstructed our commerce may be removed much more rapidly.